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(54) Objective lens and optical pickup apparatus

(57) An objective lens having a doublet structure and a numerical aperture of 0.7 or more and an optical pickup apparatus having this objective lens are adapted to an optical recording medium having a high information recording density, the objective lens being structured such that at least one side is formed into a aspheric surface and the lens elements (3, 4) are made of low-diffusion glass having an Abbe's number of 40 or greater.

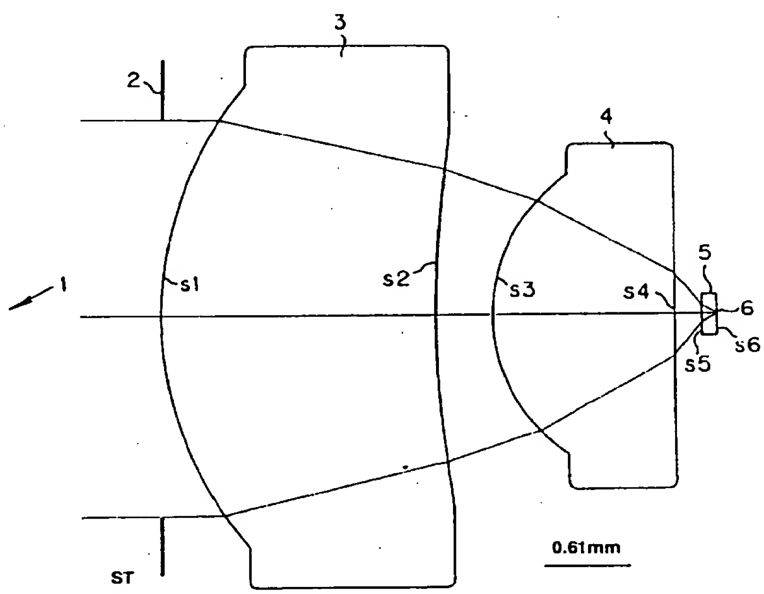

FIG.1

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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to an objective lens and an optical pickup apparatus having the objective lens and arranged to read and write an information signal to and from an optical recording medium, such as an optical disk, a magneto-optical disk or an optical card.

Description of Related Art:

Hitherto, optical recording media, such as optical disks, magneto-optical disks and optical cards, have been widely used to store data of dynamic image information, voice information and data for computers because the optical recording media can easily be manufactured and the cost can be reduced. In recent years there is a growing need to increase the density of information signals which can be recorded, and to enlarge the capacity, owing to rapid progress of the information society.

To increase the density of information signals which can be recorded on an optical recording medium of the foregoing type, the wavelength of the laser beam for reading the information signal can be shortened and the NA of the objective lens for converging the laser beam onto the optical recording medium can be increased (that is, an objective lens having a high numerical aperture, NA, can be used). The reason for this lies in that the minimum size of a beam spot, which is formed by converging the laser beam, cannot be reduced to λ/NA (λ: the wavelength of the light beam) or smaller.

To shorten the wavelength of the laser beam, a blue laser diode, a blue SHG laser and a green SHG laser have been developed. On the other hand, raising of the NA of the objective lens has been attempted by making the NA of the objective lens of a so-called "digital video disk (DVD)" (a digital optical disk adapted to a video signal), having a recording density higher than that of a so-called "compact disk (CD)" (digital optical disk adapted to an audio signal or computer data), have the value 0.6 in comparison to the NA of the "compact disk (CD)" which is 0.45. The objective lens of the optical disk is formed into an aspheric single lens (a monocyte aspheric lens) made of a synthetic resin material or a glass material.

To eliminate the influence of coma aberration occurring because of an inclination of the "digital video disk (DVD) ", the substrate of the "digital video disk (DVD)" has a thickness of 0.6 mm which is half that of the substrate of the "compact disk" and that of the magneto-optical disk.

In order to further raise the density of information signals which can be recorded, as compared with the density realised by the "digital video disk (DVD)", an objective lens having an NA higher than 0.6 is required.

However, to manufacture an objective lens having an NA not lower than 0.7, various requirements must be satisfied.

An objective lens having a high NA suffers from chromatic aberration which is attributable to change in the wavelength of a semiconductor laser (vertical-mode hop which takes place when the environmental temperature is changed). Since the conventional monocyte objective lens has an NA which is not higher than 0.6 with which chromatic aberration is not generated to such an extent, the lens of the foregoing type can be made of optical glass, the Abbe's number of which is 50 or less and which therefore has relatively high diffusion and high refractivity. Since the cost of the optical glass, having high diffusion and frequency, can be reduced, the foregoing optical glass can satisfactorily be mass-produced. Therefore, the foregoing material has been widely used.

However, high NA objective lenses of a type having an NA of 0.7 or higher suffer from great chromatic aberration if made of high diffusion optical glass. In this case excessive defocusing takes place on the surface of an optical disk on which a signal is recorded. Therefore, chromatic aberration must be prevented by using low-diffusion optical glass.

Since the major part of the low-diffusion optical glass has a low refractivity, the curvature of the surface is sharpened excessively if an objective lens having a short focal distance and a high NA is manufactured. In this case, a mould for manufacturing the lens cannot easily be machined. The present level of the technique for machining the aspheric surface cannot accurately manufacture a mould by using a diamond bit if the angle θ made between the contact surface of the aspheric surface and a plane perpendicular to the optical axis is larger than 50 degrees (according to one report, satisfactory lenses have been obtained when the angle θ is about 55 degrees or smaller).

However, an objective lens having a short focal distance and a high NA is usually designed to have the above-mentioned angle θ which exceeds 55 degrees. In this case, permissible decentering for the distance between two sides of the lens when the mould or the lens is manufactured is reduced to an excessive extent. Thus, the manufacturing efficiency deteriorates excessively.

It might therefore be considered feasible to employ a doublet lens structure to distribute the curvature to the four surfaces. However, even a doublet lens which attempts to maintain a satisfactorily long working distance involves

excessively sharp curvature of the surface. Moreover, permissible decentering between the surfaces of the lens and the permissible angle of field to be reduced when the lens is manufactured. Thus, the manufacturing efficiency deteriorates excessively. To reduce the aperture of an objective lens, that is, to reduce the diameter of an objective lens is an important issue because the reduction enables the size of the overall optical pickup apparatus to be reduced and thus an economic advantage can be realised. To maintain a sufficiently long working distance is an important factor to prevent contact between the objective lens and the optical disk which is rotated at high speed.

Therefore, the doublet objective lens must comprise a lens having a gentle curvature of the surface without deterioration in the manufacturing efficiency.

Although the curvature of the objective lens can be made to be gentle and thus the manufacturing efficiency of the objective lens can be improved if the aperture of the objective lens is enlarged, the weight of the portion including the objective lens is increased. In this case, the size of the optical pickup apparatus cannot be reduced. Moreover, the performance of the actuator (a mechanism for driving the objective lens) for moving the objective lens to follow the optical disk must be improved. In this case, the size and cost of the optical pickup apparatus cannot be reduced.

If the objective lens having a high NA is employed, there arises another problem in that the RF sign skew and the signal cannot easily be reproduced from the optical disk because the coma-aberration, which is generated due to the skew of the optical disk, is increased in proportion to the cube of the NA.

SUMMARY OF THE INVENTION

In view of the foregoing, an object of the present invention is to provide an objective lens which has a sufficiently large numerical aperture (NA), which is capable of sufficiently correcting chromatic aberration and which can easily be manufactured.

Another object of the present invention is to provide an optical pickup apparatus having the objective lens according to the present invention and arranged to be capable of satisfactorily writing and reading an information signal to and from an optical recording medium.

In order to realize the above-mentioned objects, the present invention is structured such that the chromatic aberration of a doublet lens having a high NA (numerical aperture) is reduced or avoided by using low-diffusion optical glass having an Abbe's number of 40 or more to manufacture the two lens elements. To reduce the diameter of the aperture or to obtain a satisfactorily long working distance, a first means is arranged in such a way that the first lens component having a sharper curvature is made of optical glass having a refractivity which is higher than the refractivity of optical glass for making the second lens component having a gentler curvature. Thus, the curvature can be made to be gentle and the deterioration in the manufacturing efficiency can be prevented. Since the optical glass for making the lens having the sharper curvature encounters great diffusion of wavelength in this case, a slight disadvantage is realised in view of correcting the chromatic aberration. A second means is arranged such that the aperture is limited to be 4.5 mm or smaller to reduce the aperture and the size of the optical pickup apparatus. While employing the aperture of 4.5 mm or smaller, the preferred ranges for the NA (numerical aperture), the diameter of the aperture and the working distance are limited to prevent the sharp curvature. Thus, deterioration in the manufacturing efficiency can be prevented. The above-mentioned lenses have a curvature of the surface, a tilt (inclination) and a permissible decentering which satisfy the range with which the lens can be manufactured. A thus-obtained lens is able to have optimised distribution of the refracting power of the two lens elements of the doublet lens. The distribution of the refracting power can be optimised because the manufacturing tolerance for the lens can be increased significantly if the ratio F_1/F of the focal distance F_1 of the lens adjacent to the object (adjacent to the light source) and the focal distance F of the overall system satisfies the following relationship:

$$1.7 < (F_1/F) < 2.5.$$

The optical pickup apparatus (a high-NA lens system) having the high-NA objective lens is arranged to correspond to an inclination (disk skew) of an optical recording medium by reducing the thickness of a transparent substrate (the disk substrate) to prevent generation of coma-aberration.

The present invention provides an objective lens comprising two lens elements made of optical glass having an Abbe's number of 40 or greater on a d-line and having a doublet structure, wherein at least either surface is formed into an aspheric surface and the numerical aperture is 0.7 or more.

An optical pickup apparatus according to the present invention is preferably structured such that the Abbe's number of the optical glass forming the two lens elements on the d-line is 60 or greater and the numerical aperture is made to be 0.8 or more.

An objective lens according to the present invention is preferably structured such that when an assumption is made that the refractivity (refractive index) of optical glass for forming one of the lens elements for which an angle made

between a tangential plane of a plane in the periphery of the lens element and a plane perpendicular to an optical axis is larger than the angle of the other lens element is n_1, and the refractivity of the optical glass forming the other lens element is n_2, the following relationship is satisfied:

$$n_1 > n_2.$$

An objective lens according to the present invention is preferably structured such that when an assumption is made that the diameter of an incidental laser beam is BW, the working distance is WD and the numerical aperture is NA, the following relationships are satisfied:

$$\text{if } 1.0 \le BW < 4.5,\ 0.05 \le WD \text{ and } 0.7 \le NA < 0.8,$$

then

$$WD \le 0.25676BW + 0.039189,$$

$$\text{if } 0.8 \le NA < 0.9, \text{ then } WD \le 0.14054BW - 0.064865,$$

and

$$\text{if } 0.9 \le NA, \text{ then } WD \le 0.096429BW - 0.244640.$$

An objective lens according to the present invention is preferably structured such that ratio F_1/F of focal distance F_1 of the lens disposed on the side on which a laser beam is made incident and focal distance F of the overall system of the lens satisfies the following relationship:

$$1.7 < (F_1/F) < 2.5.$$

An objective lens according to the present invention is preferably structured such that the aberration of the objective lens is corrected to correspond to thickness T of a transparent substrate of an optical recording medium disposed on a signal recording surface and supporting the signal recording surface, and the objective lens satisfies the following relationships:

$$\text{if } 0.7 \le NA \text{ (the numerical aperture)} < 0.8,$$

then

$$T \le 0.32 \text{ mm},$$

$$\text{if } 0.8 \le NA < 0.9, \text{ then } T \le 0.20 \text{ mm},$$

and

$$\text{if } 0.9 \le NA, \text{ then } T \le 0.11 \text{ mm}.$$

The present invention also provides an optical pickup apparatus comprising a light source; and an objective lens for converging a laser beam emitted from the light source onto a signal recording surface of an optical recording medium, wherein the lens has two lens elements made of optical glass having an Abbe's number of 40 or greater on a d-line

and having a doublet structure, at least either surface is formed into an aspheric surface and the numerical aperture is 0.7 or more.

An optical pickup apparatus according to the present invention is preferably structured such that the Abbe's number of the optical glass forming the two lens elements on the d-line is 60 or greater and the numerical aperture is made to be 0.8 or more.

Other objects, features and advantages of the invention will be evident from the following detailed description of the preferred embodiments described in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical cross sectional view showing a general example of an objective lens according to the present invention, made of optical glass having an Abbe's number of 50 or smaller;
FIG. 2 is a graph showing distortion of the objective lens shown in FIG. 1;
FIG. 3 is a graph showing astigmatism of the objective lens shown in FIG. 1;
FIG. 4 is a graph showing spherical aberration of the objective lens shown in FIG. 1;
FIG. 5 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 1;
FIG. 6 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 1;
FIG. 7 is a graph showing MTF (Modulation Transfer Function) of the objective lens shown in FIG. 1;
FIG. 8 is a graph showing PSF (Point Strength Function or Point Image Intensity Function) of the objective lens shown in FIG. 1;
FIG. 9 is a vertical cross sectional view showing the structure of an example of the objective lens according to the present invention in which one of the lens elements has a particularly sharp curvature;
FIG. 10 is a graph showing distortion of the objective lens shown in FIG. 9;
FIG. 11 is a graph showing astigmatism of the objective lens shown in FIG. 9;
FIG. 12 is a graph showing spherical aberration of the objective lens shown in FIG. 9;
FIG. 13 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 9;
FIG. 14 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 9;
FIG. 15 is a vertical cross sectional view showing the upper limit of the objective lens according to the present invention;
FIG 16 is a graph showing distortion of the objective lens shown in FIG. 15;
FIG. 17 is a graph showing astigmatism of the objective lens shown in FIG. 15;
FIG. 18 is a graph showing spherical aberration of the objective lens shown in FIG. 15;
FIG. 19 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 15;
FIG. 20 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 15;
FIG. 21 is a graph showing mode hop in a single mode laser diode;
FIG. 22 is a graph showing preferred ranges of the diameter of the beam, the working distance and NA (in a case where NA = 0.7);
FIG. 23 is a graph showing preferred ranges of the diameter of the beam, the working distance and NA (in a case where NA = 0.8);
FIG. 24 is a graph showing preferred ranges of the diameter of the beam, the working distance and NA (in a case where NA = 0.9);
FIG. 25 is a graph showing distribution of size of dust on an optical disk;
FIG. 26 is a histogram of the ratio F_1/F of the focal distance in an example of design in which the design tolerance is considerably large;
FIG. 27 is a graph showing the wave surface of a beam spot when the disk skew of a DVD (Digital Video Disk) is 0.4 degree;
FIG. 28 is a graph showing the thickness of a disk substrate of an optical disk which generates the wavefront aberration which is the same as that generated in FIG. 27;
FIG. 29 is a side view showing the basic components of an optical pickup apparatus according to the present invention;
FIG. 30 is a side view showing basic components of the structure of a first embodiment of the objective lens according to the present invention;
FIG. 31 is a graph showing distortion of the objective lens shown in FIG. 30;
FIG. 32 is a graph showing astigmatism of the objective lens shown in FIG. 30;
FIG. 33 is a graph showing spherical aberration of the objective lens shown in FIG. 30;
FIG. 34 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 30;
FIG. 35 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 30;
FIG. 36 is a graph showing MTF (Modulation Transfer Function) of the objective lens shown in FIG. 30;

FIG. 37 is a graph showing the PSF (Point Strength Function or Point Image Intensity Function) of the objective lens shown in FIG. 30;
FIG. 38 is a vertical cross sectional view showing the structure of a second embodiment of the objective lens according to the present invention;
FIG. 39 is a graph showing distortion of the objective lens shown in FIG. 38;
FIG. 40 is a graph showing astigmatism of the objective lens shown in FIG. 38;
FIG. 41 is a graph showing spherical aberration of the objective lens shown in FIG. 38;
FIG. 42 is a graph showing lateral aberration (angle of view: 0.5 degree) ofthe objective lens shown in FIG. 38;
FIG. 43 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 38;
FIG. 44 is a vertical cross sectional view showing the structure of a third embodiment of the objective lens according to the present invention;
FIG. 45 is a graph showing distortion of the objective lens shown in FIG. 44;
FIG. 46 is a graph showing astigmatism of the objective lens shown in FIG. 44;
FIG. 47 is a graph showing spherical aberration of the objective lens shown in FIG. 44;
FIG. 48 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 44;
FIG. 49 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 44;
FIG. 50 is a vertical cross sectional view showing the structure of a fourth embodiment of the objective lens according to the present invention;
FIG. 51 is a graph showing distortion of the objective lens shown in FIG. 50;
FIG. 52 is a graph showing astigmatism of the objective lens shown in FIG. 50;
FIG. 53 is a graph showing spherical aberration of the objective lens shown in FIG. 50;
FIG. 54 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 50;
FIG. 55 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 50;
FIG. 56 is a vertical cross sectional view showing the structure of a fifth embodiment of the objective lens according to the present invention;
FIG. 57 is a graph showing distortion of the objective lens shown in FIG. 56;
FIG. 58 is a graph showing astigmatism of the objective lens shown in FIG. 56;
FIG. 59 is a graph showing spherical aberration of the objective lens shown in FIG. 56;
FIG. 60 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 56;
FIG. 61 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 56;
FIG. 62 is a vertical cross sectional view showing the structure of a sixth embodiment of the objective lens according to the present invention;
FIG. 63 is a graph showing distortion of the objective lens shown in FIG. 62;
FIG. 64 is a graph showing astigmatism of the objective lens shown in FIG. 62;
FIG. 65 is a graph showing spherical aberration of the objective lens shown in FIG. 62;
FIG. 66 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 62;
FIG. 67 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 62;
FIG. 68 is a vertical cross sectional view showing the structure of a seventh embodiment of the objective lens according to the present invention;
FIG. 69 is a graph showing distortion of the objective lens shown in FIG. 68;
FIG. 70 is a graph showing astigmatism of the objective lens shown in FIG. 68;
FIG. 71 is a graph showing spherical aberration of the objective lens shown in FIG. 68;
FIG. 72 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 68;
FIG. 73 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 68;
FIG. 74 is a vertical cross sectional view showing the structure of an eighth embodiment of the objective lens according to the present invention;
FIG. 75 is a graph showing distortion of the objective lens shown in FIG. 74;
FIG. 76 is a graph showing astigmatism of the objective lens shown in FIG. 74;
FIG. 77 is a graph showing spherical aberration of the objective lens shown in FIG. 74;
FIG. 78 is a graph showing lateral aberration (angle of view: 0.5 degree) ofthe objective lens shown in FIG. 74;
FIG. 79 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 74;
FIG. 80 is a vertical cross sectional view showing the structure of a ninth embodiment of the objective lens according to the present invention;
FIG. 81 is a graph showing distortion of the objective lens shown in FIG. 80;
FIG. 82 is a graph showing astigmatism of the objective lens shown in FIG. 80;
FIG. 83 is a graph showing spherical aberration of the objective lens shown in FIG. 80;
FIG. 84 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 80;
FIG. 85 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 80;

FIG. 86 is a vertical cross sectional view showing the structure of a tenth embodiment of the objective lens according to the present invention;
FIG. 87 is a graph showing distortion of the objective lens shown in FIG. 86;
FIG. 88 is a graph showing astigmatism of the objective lens shown in FIG. 86;
FIG. 89 is a graph showing spherical aberration of the objective lens shown in FIG. 86;
FIG. 90 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 86;
FIG. 91 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 86;
FIG. 92 is a vertical cross sectional view showing the structure of an eleventh embodiment of the objective lens according to the present invention;
FIG. 93 is a graph showing distortion of the objective lens shown in FIG. 92;
FIG. 94 is a graph showing astigmatism of the objective lens shown in FIG. 92;
FIG. 95 is a graph showing spherical aberration of the objective lens shown in FIG. 92;
FIG. 96 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 92;
FIG. 97 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 92;
FIG. 98 is a vertical cross sectional view showing the structure of a twelfth embodiment of the objective lens according to the present invention;
FIG. 99 is a graph showing distortion of the objective lens shown in FIG. 98;
FIG. 100 is a graph showing astigmatism of the objective lens shown in FIG. 98;
FIG. 101 is a graph showing spherical aberration of the objective lens shown in FIG. 98;
FIG. 102 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 98;
FIG. 103 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 98;
FIG. 104 is a vertical cross sectional view showing the structure of a thirteenth embodiment of the objective lens according to the present invention;
FIG. 105 is a graph showing distortion of the objective lens shown in FIG. 104;
FIG. 106 is a graph showing astigmatism of the objective lens shown in FIG. 104;
FIG. 107 is a graph showing spherical aberration of the objective lens shown in FIG. 104;
FIG. 108 is a graph showing lateral aberration (angle of view: 0.5 degree) of the objective lens shown in FIG. 104; and
FIG. 109 is a graph showing the lateral aberration (on the axis) of the objective lens shown in FIG. 104.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present invention will now be described with reference to the drawings in the following sequential order.

1. Schematic structure of objective lens
2. Lens of a type using low-diffusion optical glass which has Abbe's number νd not smaller than 40 ($\nu d \geq 40$) on d-line as the optical glass of two lens elements.
3. Lens satisfying $n_1 > n_2$ on an assumption that the refractivity of the lens component having a sharper curvature is n_1 and the refractivity of the lens component having a gentler curvature is n_2.
4. Lens having beam diameter BW and working distance WD limited as follows:

$$\text{if } 1.0 \leq BW < 4.5,\ 0.05 \leq WD \text{ and } 0.7 \leq NA \text{ (the numerical aperture)} < 0.8,$$

then

$$WD \leq 0.25676BW + 0.039189,$$

$$\text{if } 0.8 \leq NA < 0.9,$$

then

$$WD \leq 0.14054BW - 0.064865,$$

and

$$\text{if } 0.9 \le NA,$$

then

$$WD \le 0.096429BW - 0.244640$$

4-1. Upper limit of the diameter of the beam
4-2. Lower limit of the working distance
4-3. Upper limit of the working distance

5. Lens in which the ratio (F_1/F) of focal distance F_1 of the lens adjacent to an object (adjacent to the light source) and focal distance F of the overall system satisfies $1.7 < (F_1/F) < 2.5$.
6. Lens corrected to correspond to thickness T of a transparent substrate of an optical recording medium as follows:

$$\text{if } 0.7 \le NA \text{ (the numerical aperture)} < 0.8,$$

then

$$T \le 0.32 \text{ mm},$$

$$\text{if } 0.8 \le NA < 0.9,$$

then

$$T \le 0.20 \text{ mm},$$

and

$$\text{if } 0.9 \le NA,$$

then

$$T \le 0.11 \text{ mm}.$$

7. Structure of optical pickup apparatus
8. Modification

1. Schematic Structure

The objective lens according to the present invention is a doublet lens (two elements in two groups) having at least either side formed into an aspheric surface, as shown in FIG. 1 and Table 1, the objective lens according to the present invention being a high-NA (the numerical aperture) objective lens having an NA of 0.7 or more. That is, the objective lens according to the present invention comprises a first lens 3 disposed adjacent to an object (e.g. adjacent to the light source when used in an optical disk recording/reading apparatus) and a second lens 4 disposed adjacent to an image (e.g. an optical recording medium). The parallel flat plate 5 shown in FIG. 1 corresponds to a transparent portion of an optical recording medium which may be used with the objective lens according to the present invention; plate 5 is located at a position adjacent to the image.

The objective lens according to the present invention is a so-called infinite lens having an object point (OBJ) (light

source) positioned at an infinitely distant position. When the objective lens of the present invention is used for reading an optical recording medium, a light beam emitted from the object point (e.g. a laser beam) is formed into a parallel beam, and then allowed to pass through a stop (STO) 2 so that the laser beam is made incident on first surface S1 (an incident surface of the first lens 3). The laser beam is then emitted from second surface S2 (an emission surface of the first lens 3), and then made incident on third surface S3 (an incident surface of the second lens 4). The laser beam is then emitted from fourth surface S4 (an emission surface of the second lens 4), and then made incident on fifth surface S5 (an incident surface of the parallel flat plate 5). The laser beam is then imaged on an imaging point 6 or IMG on a sixth surface S6 (an emission surface of the parallel flat plate 5).

[Table 1]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.41728	1.920128	731.405
	K:-0.098342 A:-.335213E-02 B:-.612803E-03 C:-.167781E-03 D:-.786690E-04 E:0.145905E-04 F:-.103594E-04		
s2	6.10659	0.381566	
	K:-5.574578 A:0.266412E-02 B:-.160850E-02 C:-.152011E-02 D:-.183517E-02 E:0.275197E-03 F:0.258063E-03		
s3	1.135	1.268447	731.405
	K:-0.113115 A:0.564267E-02 B:-.239467E-02 C:0.536980E-02 D:-.139509E-01 E:-.831405E-02 F:0.194854E-02		
s4	2.22598	0.2	
	K:-34.597713 A:-.172244E+00 B:0.317741E+00 C:0.543683E+01 D:-.295791E+02 E:0.127036E-15 F:0.951503E-17		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

[Table 1] (continued)

Equation of Aspheric Surface	
E : aspheric coefficient of term Y^{12} F : aspheric coefficient of term Y^{14}	
EPD (Diameter of Entrance Pupil (mm))	2.928
WL (Wavelength (nm))	635.0
Refractivity/ Abbe's Number Name of Glass 731.405 CG	 1.727/40.5 1.533
F (Focal Distance of Overall System)	1.83
F_1 (Focal Distance of Lens adjacent to Object)	4.5136

A graph showing distortion of the objective lens according to the present invention is shown in FIG. 2, that showing astigmatism of the same is shown in FIG. 3 and that showing spherical aberration of the same is shown in FIG. 4. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 5 and that showing the lateral aberration (on the axis) is shown in FIG. 6.

<u>2. Lens of a type using low-diffusion optical glass which has Abbe's number vd not smaller than 40 (vd ≥ 40) on d-line as optical glass of two lens elements</u>

Since the objective lens according to the present invention responds to change in the wavelength of the semiconductor laser, which is the light source, because the objective lens according to the present invention has a high NA, correction of the chromatic aberration must be considered. The chromatic aberration is aberration which is generated because the refractivity of the optical glass becomes different according as the wavelength of light. The position and size of the image become different according as the wavelength.

Since the conventional objective lens having a low NA for use in an optical disk, such as the conventional CD (Compact Disk), or a laser beam printer does not generate a large quantity of the chromatic aberration, optical glass (having an Abbe's number smaller than 40) is widely used. The reason for this lies in that the above-mentioned optical glass can easily be manufactured and thus mass production is permitted.

However, the lens system has higher refracting power in proportion to the NA and thus the chromatic aberration takes place considerably attributable to change in the refractivity occurring when the wavelength has been changed. Moreover, the chromatic aberration takes place considerably in a long focal distance system.

On the other hand, the semiconductor laser encounters mode hop as shown in FIG. 21 according as the change in the temperature of the laser diode and thus the output wavelength is rapidly changed. If chromatic aberration is generated in the objective lens, defocus occurring attributable to the mode hop cannot be followed and removed by a biaxial actuator for moving the objective lens.

Accordingly, the lens must be made of low-diffusion optical glass to prevent generation of the chromatic aberration. The objective lens designed as described above, as shown in FIG. 1 and Table 1, comprises the first and second lenses 3 and 4 both of which have an Abbe's number vd of 40.5 and a refractivity of 1.73. When the degree of opening is limited by the stop 2, defocus with respect to change in the wavelength of a + 5 nm semiconductor laser is 0.478 μm when the NA is 0.8.

An MTF (Modulation Transfer Function) in the direction of the optical axis when the spatial frequency is 80/mm is shown in FIG. 7, and PSF (Point Strength Function) is shown in FIG. 8.

If a high NA objective lens adaptable to an optical disk serving as an optical recording medium generates defocus greater than 0.496 μm which is half of the focal depth of 0.992 μm when the wavelength of the semiconductor laser has been changed by P-P10 nm (± 5 nm), the beam spot on the signal recording surface of the optical disk cannot completely be stopped. When the wavelength has been changed by P-P10 nm (± 5 nm), the lens made of the optical glass shown in FIG. 1 and having the Abbe's number vd of 40.5 generates defocus of 0.475 μm which is substantially the permissible defocus. Therefore, the present invention is structured such that the lower limit of the proper Abbe's number vd of the optical glass for making the lens is made to be 40 in order to prevent chromatic aberration. It is

preferable that the upper limit of the Abbe's number vd be a large value to prevent the chromatic aberration. Therefore, the present invention is structured such that the range of the Abbe's number vd of the optical glass for manufacturing the lens having the NA of 0.7 or more is determined to be 40 or larger to effectively prevent the chromatic aberration.

In a first embodiment to be described later, an example of an objective lens made of optical glass having a larger Abbe's number (vd = 61.3) will be described. In this case, the chromatic aberration can be prevented even if the focal distance is elongated or the NA is enlarged.

3. Lens satisfying $n_1 > n_2$ on an assumption that the refractivity of the lens having sharper curvature is n_1 and the refractivity of the lens having gentler curvature is n_2.

Even if the chromatic aberration is prevented by using the above-mentioned low-diffusion optical glass, there arises the following problem: the curvature of the lens is sharpened too excessively to permit manufacture of the lens if the low-diffusion optical glass having a low refractivity is used because large refracting force is required for the optical glass for manufacturing the objective lens having a high NA. In this case, the optical glass must be changed to raise the refractivity and to enable the curvature to be gentle.

In this case diffusion in the available optical glass however deteriorates. Therefore, the two lenses must be made of optical glass having the Abbe's number of 40 or larger. If optical glass having a larger Abbe's number is employed to manufacture the lens having a gentle curvature and if the optical glass having a smaller Abbe's number (however not less than 40) is employed to manufacture the lens having sharper curvature, deterioration in the chromatic aberration can be prevented most significantly.

The state where the curvature is too sharp to manufacture the lens is a state where the angle θ made between a tangent (a tangential plane) of the surface of a lens at a position, on which a laser beam which has the largest height among the incident laser beams is made incident, and a perpendicular (a plane perpendicular to the optical axis) to the optical axis exceeds 55 degrees (65 degrees in the case shown in FIG. 9) on the surface (plane S3 in the case shown in FIG. 9) having the sharpest curvature as shown in FIG. 9. In this case, a mould for manufacturing the foregoing lens cannot accurately be manufactured. The designed values of the objective lens shown in FIG. 9 are as shown in Table 2.

[Table 2]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	0.65323	0.471733	FCD1
	K:-0.143186 A:-.239735E+00 B:-.409752E+00 C:-.277114E+00 D:-.167201E+01 E:0.337892E+01 F:-.405421E+02		
s2	-6.89267	0.002068	
	K:-490.930053 A:0.188677E-01 B:0.377014E-01 C:-.110654E+01 D:0.199457E+01 E:-.181894E+02 F:0.288857E+02		
s3	0.36152	0.451734	FCD1
	K:-0.024229 A:0.152164E+00 B:0.250036E+01 C:-.916245E+01 D:0.348714E+02 E:0.146318E-03 F:0.299313E-03		
s4	0.90849	0.05	
	K:-192.038095 A:0.160336E+02 B:-.113006E+04 C:0.384911E+05		
	D:-.487143E+06 E:0.873041E-11 F:0.321727E-11		
s5	Infinity	0.1	CG

[Table 2] (continued)

	D:-.487143E+06 E:0.873041E-11 F:0.321727E-11		
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y / R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	0.977
WL (Wavelength (nm))	635
Refractivity/ Abbe's Number Name of Glass	
FCD 1	1.494122/81.6
CG	1.533
F (Focal Distance of Overall System)	0.5747
F_1 (Focal Distance of Lens adjacent to Object)	1.2331

A graph showing distortion of the foregoing objective lens is shown in FIG. 10, astigmatism of the same is shown in FIG. 11 and spherical aberration of the same is shown in FIG. 12. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 13 and a graph showing the lateral aberration (on the axis) is shown in FIG. 14.

As described above, the curvature of the lens is made to be gentle to satisfy the range with which the lens can be manufactured, while satisfactorily preventing the chromatic aberration, so that the efficiency of manufacturing the lens is effectively improved.

An objective lens designed as described above will be described below as a second embodiment.

4. Lens having beam diameter BW and working distance WD limited as follows:

if 1.0 ≤ BW < 4.5, 0.05 ≤ WD and 0.7 ≤ NA (the numerical aperture) < 0.8, then WD ≤ 0.25676BW + 0.039189, if 0.8 ≤ NA < 0.9, then WD ≤ 0.140548W - 0.064865, and if 0.9 ≤ NA, then WD ≤ 0.096429BW - 0.244640.

The doublet objective lens, in order to be adaptable to an optical recording medium such as an optical disk, is preferably required to have a reduced aperture (a shortened focal distance) in order to reduce the size and cost of the optical pickup apparatus. Since the objective lens according to the present invention is composed of two lens elements, reduction in the aperture is an important issue. The reason for this lies in that the weight of the foregoing lens is increased as compared with a single-element lens if the aperture is large.

If the aperture of a large-diameter lens is simply reduced, the working distance WD is undesirably shortened. In practice, the reduction cannot sometimes be performed as desired because at least a working distance of 50 μm must be provided to prevent contact between the objective lens and dust on the surface of the optical recording medium. If provision of a satisfactorily long working distance is attempted, the quantity of correction of the spherical aberration is increased excessively. In this case, the aspheric coefficient is increased and the curvature of the surface is rapidly sharpened. As a result, the manufacturing efficiency deteriorates.

The limit for reducing the aperture is made to be different depending upon the NA, as well as the working distance. The reason for this lies in that the quantity of correction of the spherical aberration varies depending upon the NA of the lens.

From the viewpoint of designing and manufacturing a lens, a lens having improved performance can easily be manufactured when the aperture is large.

Therefore, ranges of the diameter of the beam, the working distance (WD) and NA suitable to manufacture the doublet lens will now be described with reference to FIGS. 22 to 24.

4-1. Upper Limit of Diameter of Beam

As indicated with A shown in FIGS. 22 and 24, the upper limit of the diameter of the beam is determined. If the diameter of the beam is large, the size of the optical pickup apparatus cannot be reduced and the weight of the objective lens and that of the lens barrel (the lens holder) are enlarged. In this case, the actuator for performing focus servo must have improved performance, which is disadvantageous from an economic viewpoint.

For example an objective lens shown in FIG. 15 having an effective beam diameter of 4.5 mm and comprising two lens elements has a large weight of about 250 mg. The weight of an objective lens adapted for use with CDs (Compact Disks) or DVDs (Digital Video Disks) is about 200 mg including the lens housing. Since the relationship f = k/2m (m: mass k: spring constant and f: resonant frequency) is satisfied in consideration of the performance of the biaxial actuator preferably for servo control because f is brought to a position outside the focus servo. If the preferred overall weight of the objective lens including the lens housing is made to be 500 mg or smaller, a lens having a weight of 500 mg or smaller including the lens housing cannot easily be designed in the case of a lens heavier than the objective lens having an effective diameter of 4.5 mm and shown in FIG. 15 having a weight of 250 mg. In this case, the biaxial actuator must have improved performance and the manufacturing cost is raised excessively for practical use. Therefore, it is preferable that the effective diameter of the doublet lens be 4.5 mm or smaller.

Design data for the objective lens shown in FIG. 15 is shown in Table 3. A graph showing distortion of the foregoing objective lens is shown in FIG. 16, astigmatism of the same is shown in FIG. 17 and spherical aberration of the same is shown in FIG. 18. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 19 and a graph showing the lateral aberration (on the axis) is shown in FIG. 20.

[Table 3]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.46917	3.042666	FCD1
	K:-0.177274		
	A:-.353215E-02 B:-.452433E-03 C:-.556160E-05		
	D:-.991159E-05 E:-.128023E-07 F:-.159371E-06		
s2	-12.58525	0.491772	
	K:-13.032252		
	A:0.307368E-02 B:0.799138E-04 C:0.242782E-03		
	D:-.981829E-04 E:-.324027E-04 F:0.162258E-04		
s3	1.25000	1.481326	BK7
	K:0.0		
	A:0.0 B:0.0 C:0.0		
	D:0.0 E:0.0 F:0.0		

[Table 3] (continued)

Surface	RDY (Curvature Radius)			THI (Thickness)	GLA (Name of Glass)
s4	Infinity			0.1	
	K:0.0				
	A:0.0	B:0.0	C:0.0		
	D:0.0	E:0.0	F:0.0		
s5	Infinity			0.1	CG
s6	Infinity			0.0	
IMG	Infinity			0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface
Y : height from optical axis
R : paraxis R
K : cone constant
A : aspheric coefficient of term Y^4
B : aspheric coefficient of term Y^6
C : aspheric coefficient of term Y^8
D : aspheric coefficient of term Y^{10}
E : aspheric coefficient of term Y^{12}
F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	4.5000
WL (Wavelength (nm))	635
Refractivity/ Abbe's Number Name of Glass	
FCD1	1.494122/81.6
BK7	1.515014
CG	1.533
F (Focal Distance of Overall System)	2.3684
F_1 (Focal Distance of Lens adjacent to Object)	4.4767

4-2. Lower Limit of Working Distance

The lower limit of the working distance WD is determined as indicated with B shown in FIGS. 22 to 24. Since the

quantity of correction of the spherical aberration can be reduced in proportion to the working distance, the lens can easily be manufactured. From the viewpoint of actual use, a certain working distance must be provided in order to prevent a collision between the objective lens and an optical recording medium, for example, an optical disk which is being rotated at high speed, when focus search is performed, or contact between dust on the surface of the optical recording medium and the objective lens when focus servo is started.

Sizes (diameters) of dust on the surface of the optical recording medium allowed to stand in an environment of a room are usually 50 μm or smaller, as shown in FIG. 25. Therefore, the working distance must be 50 μm or greater.

4-3. Upper Limit of Working Distance

The quantity of the spherical aberration, which can be corrected by the doublet lens, with respect of a certain NA and the diameter of the beam depends on the working distance. In the present invention, various lenses are designed in consideration of the curvature (the angle θ is 55 degrees or more), the permissible decentering (± 10 μm or more) and permissible angle of view (1 degree or more): Examples of the upper limit of the working distance realizing the above-mentioned permissible ranges are as indicated with points 1 to 9 shown in FIGS. 22 to 24. If the working distance exceeds the above-mentioned upper limits, the spherical aberration is increased excessively and therefore the curvature of the lens is sharpened excessively. Therefore, if the design is performed in such a way that the working distance is not included in the shaded regions shown in FIGS. 22 to 24, the lens cannot easily be manufactured or the lens cannot be used with the optical recording medium. The preferred ranges are expressed with linear approximation performed on the basis of the designed examples, as follows:

$$\text{If } 1.0 \leq BW < 4.5,\ 0.05 \leq WD \text{ and } 0.7 \leq NA < 0.8, \text{ then } WD \leq 0.25676BW + 0.039189 \text{ (see FIG. 22).}$$

$$\text{If } 0.8 \leq NA < 0.9, \text{ then } WD \leq 0.14054BW - 0.064865 \text{ (see FIG. 23).}$$

$$\text{If } 0.9 \leq NA, \text{ then } WD \leq 0.096429BW - 0.244640 \text{ (see FIG. 24).}$$

The permissible decentering (± 10 μm or more) is a value determined on the basis of the accuracy when the lens is manufactured by injection moulding using a mould. The permissible angle of view (1 degree or more) is a value determined on the basis of the mounting accuracy about inclination of the doublet lens relative to the optical axis.

Objective lenses satisfying the above-mentioned conditions shown in FIGS. 22 to 24 will be described below such that the objective lens corresponding to point 2 shown in FIG. 22 will be described as an eighth embodiment, that corresponding to point 3 shown in FIG. 22 will be described as a ninth embodiment and that corresponding to point 9 shown in FIG. 24 will be described as a tenth embodiment.

5. Lens in which the ratio (F_1/F) of focal distance F_1 of the lens adjacent to an object (adjacent to the light source) and focal distance F of the overall system satisfies $1.7 < (F_1/F) < 2.5$

The above-mentioned lens is a lens designed to optimally distribute the refracting power of the two lens elements to realize a satisfactory manufacturing efficiency of the lens, that is, the curvature of the surface, the permissible decentering and the permissible angle of view in the range in which the lens can be manufactured. When the state of distribution of the refracting power, which is expressed with the ratio (F_1/F) of the focal distance F_1 of the first lens (the lens adjacent to the object) 3 and the focal distance F of the overall system satisfies the following range,

$$1.7 < (F_1/F) < 2.5,$$

a satisfactorily great manufacturing tolerance for the lens can be obtained and the refracting power can be distributed optimally.

The foregoing fact indicates that the optimum power distribution is achieved when the power of the first lens (lens adjacent to the object) 3 is about ½ of the power of the overall system.

If $(F_1/F) \leq 1.7$, the focal distance F_1 of the first lens (the lens adjacent to the object) 3 is short, that is, the power is great. In this case the curvature, the permissible decentering and the permissible tilt for the first lens (the lens adjacent to the object) 3 are made to be strict. If $2.5 \leq (F_1/F)$, the focal distance F_1 of the first lens (the lens adjacent to the object) 3 is elongated and the power is reduced. However, the power of the second lens (lens adjacent to the image)

4 is increased. In this case, the curvature, the permissible decentering and the permissible tilt are made to be strict.

When only the manufacturing tolerance for the lens is considered, the above-mentioned range is sometimes widened in accordance with the NA, the effective diameter of the beam and the working distance. As a result of design and investigation of various lenses and manufacturing tolerances, a histogram relating to the lenses which permitted great manufacturing tolerance was obtained, as shown in FIG. 26. That is, the power distribution can be performed optimally and the manufacturing tolerance can significantly be widened if the following relationship is satisfied:

$$1.7 < (F_1/F) < 2.5.$$

A lens satisfying the above-mentioned relationship will be described below as a third embodiment.

6. Lens corrected to correspond to thickness T of a transparent substrate of an optical recording medium as follows:

if $0.7 \leq NA$ (the numerical aperture) < 0.8, then $T \leq 0.32$ mm, if $0.8 \leq NA < 0.9$, then $T \leq 0.20$ mm, and if $0.9 \leq NA$, then $T \leq 0.11$ mm.

The optical recording medium, for example, the optical disk, for use in the optical pickup apparatus to which the objective lens according to the present invention is applied has a transparent substrate (the disk substrate) having a thickness of 0.1 mm which is significantly smaller than 1.2 mm which is the thickness of the conventional CD (Compact Disk) and 0.6 mm which is the thickness of the DVD (Digital Video Disk). The reason for this lies in that the skew margin is equivalent or superior to the skew margin realised by the conventional structure by reducing the coma-aberration which is generated due to the skew of the optical recording medium. Since the quantity of the coma-aberration, which is generated due to the disk skew, is increased in proportion to the cube of the NA, a little disk skew rapidly deteriorates the RF when a signal is read by using a high-NA objective lens.

$$W_{31} = (T(n^2 - 1)\,n^2 \sin\theta\cos\theta s)/(2\,(n^2 - \sin^2\theta s)^{(5/2)})$$
$$\fallingdotseq (T(n^2 - 1)NA^3\theta s)/(2n^3)$$

where n: refractivity of transparent substrate, T: thickness of transparent substrate and θs: angle of skew.

As can be understood from the above-mentioned equation, the coma-aberration is enlarged in proportion to the thickness T of the transparent substrate. Therefore, reduction in the thickness T of the transparent substrate is an effective means to overcome the skew. An objective lens (NA = 0.6) adapted to the DVD (Digital Video Disk) (comprising the disk substrate having a thickness of 0.6 mm) generates wavefront aberration of about 0.043 rms on the imaging surface as shown in FIG. 27 when a skew (a radial skew) having a skew angle θs = 0.4 degree exists. When a skew (a radial skew) of θs = 0.4 degree exists when NA is enlarged to exceed 0.6, the wavefront aberration on the imaging surface is made to be 0.043 rms by making the thickness of the transparent substrate to be about 0.32 mm in a case where the NA is 0.7, about 0.20 mm in a case where the NA is 0.8 to 0.9 and about 0.11 mm in a case where the NA is 0.9, as shown in FIG. 28. If the thickness of the transparent substrate is smaller than the above-mentioned values, the wavefront aberration can furthermore be reduced.

7. Structure of Optical Pickup Apparatus

The optical pickup apparatus according to the present invention may be an apparatus for reproducing an optical disk 12, as shown in FIG. 29. The optical pickup apparatus has the objective lens according to the present invention.

A linearly polarised light beam emitted from a semiconductor laser (not shown) which is a light source, made to be a parallel light beam and having a wavelength of 635 nm is allowed to pass through a polarising beam splitter (PBS) 7 and a λ/4 (1/4-wavelength) plate 8 so as to be brought into a circularly polarised state. The circularly polarised laser beam is allowed to pass through the objective lens and the disk substrate 5 so as to be converged on the signal recording surface of the optical disk 12. The disk substrate 5 is a thin substrate having a thickness of 0.1 mm. The foregoing objective lens is a lens formed by combining two aspheric lenses 3 and 4 and having an NA of 0.7 to 0.95.

The above-mentioned optical disk 5, 12 is a single-layered or a multilayered disk manufactured by bonding a glass plate having a thickness of 1.2 mm to reinforce the strength of the disk substrate 5 having a thickness of 0.1 mm.

The laser beam reflected by the signal recording surface is returned through the original optical path, and then allowed to pass through the λ/4 plate 8. Thus, the laser beam is made to be a linearly polarised laser beam rotated by 90 degrees from the forward linearly polarised direction. The laser beam is reflected by the linearly polarising beam splitter 7, and then allowed to pass through a focusing lens (a converging lens) 13 and a multilens 14 so as to be

detected as an electric signal by a photodetector (PD) 15.

The multilens 14 typically has an incident surface formed as a cylindrical surface and an emission surface formed into a concave shape. The multilens 14 realises astigmatism for enabling a focus error signal to be detected from the incidental laser beam by a so-called astigmatism method. The photodetector 15 typically is a photodiode having six elements arranged to output electric signals for performing the focus adjustment by the astigmatism method and the tracking adjustment by a so-called 3-beam method.

8. Modification

The objective lens according to the present invention is not limited to the lens of the so-called infinite system having an object point (the light source). The objective lens may be designed as a finite-system lens structured such that the object point (the light source) is positioned for a finite distance.

Embodiments

Embodiments of the objective lens according to the present invention will now be described. In the embodiments, the material for manufacturing the transparent substrate 5 is CG (having a refractivity of 1.533 when the wavelength is 635 nm and 1.5769 when the wavelength is 680 nm).

First Embodiment

An objective lens according to this first embodiment is shown in FIG. 30 and has a structure in which the lenses 3 and 4 are manufactured by low-diffusion optical glass (BACD5) having an Abbe's number vd of 61.3 on the d-line and a refractivity of 1.589.

A graph showing distortion of the foregoing objective lens is shown in FIG. 31, astigmatism of the same is shown in FIG. 32 and spherical aberration of the same is shown in FIG. 33. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 34 and a graph showing the lateral aberration (on the axis) is shown in FIG. 35.

When the NA is made to be 0.8 by limiting the opening by using the stop 2, defocus with respect to change in the wavelength of the + 5 nm semiconductor laser is 0.331 μm. The MTF (Modulation Transfer Function) when the spatial frequency in the direction of the optical axis near the imaging point is 80/mm is shown in FIG. 36 and PSF (point image intensity function) is shown in FIG. 37. As can be understood from FIG. 36, the peak of the degree of modulation is shifted and defocused from the focus position 0.0.

The conditions of the design are as shown in Table 4. The lens according to this embodiment is able to satisfactorily prevent chromatic aberration even if the focal distance is elongated or even if the NA is enlarged.

[Table 4]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.20755	1.936777	BACD5
	K:-0.113185 A:-.352973E-02 B:-.927936E-03 C:-.279329E-03 D:-.444713E-04 E:-.158207E-05 F:-.142540E-04		
s2	7.47812	0.173619	
	K:0.799767 A:0.402205E-02 B:-.177572E-02 C:-.169497E-02 D:-.116911E-02 E:-.260040E-03 F:0.313890E-03		
s3	1.07896	1.398201	BACD5
	K:-0.089540 A:-.767323E-04 B:0.278212E-02 C:-.471041E-02 D:-.133615E-02 E:0.114466E-02 F:-.523864E-02		

[Table 4] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s4	6.15302	0.200	
	K:-1022.954450 A:0.352446E+00 B:-.575917E+00 C:0.111774E+01 D:0.174499E+01 E:0.203429E-12 F:0.12891E-13		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	
Equation of Aspheric Surface $X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$ X : depth from vertex of surface Y : height from optical axis R : paraxis R K : cone constant A : aspheric coefficient of term Y^4 B : aspheric coefficient of term Y^6 C : aspheric coefficient of term Y^8 D : aspheric coefficient of term Y^{10} E : aspheric coefficient of term Y^{12} F : aspheric coefficient of term Y^{14}			
EPD (Diameter of Entrance Pupil (mm))	2.928		
WL (Wavelength (nm))	635.0		
Refractivity/ Abbe's Number Name of Glass			
BACD5	1.587007/61.3		
CG	1.533		
F (Focal Distance of Overall System)	1.83		
F_1 (Focal Distance of Lens adjacent to Object)	4.6974		

Second Embodiment

An objective lens according to this embodiment is shown in FIG. 38 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCDI) having an Abbe's number vd on the d-line of 81.6 and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 39, astigmatism of the same is shown in FIG. 40 and spherical aberration of the same is shown in FIG. 41. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 42 and a graph showing the lateral aberration (on the axis) is shown in FIG. 43. The conditions of the design are as shown in Table 5. The objective lens according to this embodiment is structured

in such a manner that the optical glass having a higher refractivity is employed to manufacture the second lens (the lens adjacent to the image) 4 as compared with that of the first lens (the lens adjacent to the object) 3. Thus, the chromatic aberration is prevented satisfactorily and the curvature of the second lens (the lens adjacent to the image) 4 is made to be gentle so that machining of the lens is performed easily.

[Table 5]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.15182	2.085603	FCD1
	K:-0.133331 A:-.396302E-02 B:-.136579E-02 C:-.269158E-03 D:-.140877E-04 E:0.130101E-05 F:-.148648E-04		
s2	8.28264	0.311261	
	K:-3.211588 A:0.307942E-02 B:-.169672E-02 C:-.152057E-02 D:-.710548E-03 E:-.165963E-03 F:0.261243E-03		
s3	1.08326	1.436933	BACD5
	K:-0.090747 A:-.933930E-03 B:-.405559E-02 C:-.606131E-02 D:-.497401E-02 E:-.318784E-02 F:-.784888E-02		
s4	-4.03999	0.2000	
	K:-1932.300730 A:0.180398E+00 B:-.249506E+00 C:-.392373E+00 D:0.245165E+01 E:0.203472E-12 F:0.124909E-13		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

[Table 5] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
EPD (Diameter of Entrance Pupil (mm))		2.928	
WL (Wavelength (nm))		635.0	
Name of Glass FCD1 BACD5 CG		Refractivity/Abbe's Number 1.494122/81.6 1.587007/61.3 1.533	
F (Focal Distance of Overall System)		1.83	
F_1 (Focal Distance of Lens adjacent to Object)		5.2884	

Third embodiment

An objective lens according to this embodiment is shown in FIG. 44 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCDI) having an Abbe's number vd of 81.6 and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 45, astigmatism of the same is shown in FIG. 46 and spherical aberration of the same is shown in FIG. 47. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 48 and a graph showing the lateral aberration (on the axis) is shown in FIG. 49. The conditions of the design are as shown in Table 6. The objective lens according to this embodiment satisfies the above-mentioned conditions as $1.7 < (F_1/F) < 2.5$. Therefore, the design according to this embodiment enables the power distribution to be made optimally and the manufacturing tolerance for the lenses 3 and 4 to be increased.

[Table 6]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	1.90838	1.567111	FCD1
	K:-0.192781 A:-.584096E-02 B:-.154354E-02 C:-.224902E-03 D:-.150574E-03 E:0.499346E-04 F:-.163557E-04		
s2	-47.77042	0.535335	
	K:-1884.160827 A:0.206660E-02 B:-.614175E-03 C:0.604320E-04 D:-.157033E-03 E:0.678618E-04 F:0.497349E-04		
s3	1.1174	1.350462	BACD5
	K:-0.121891 A:0.240825E-02 B:-.204726E-02 C:0.143610E+01 D:-.299060E-01 E:0.623946E-02 F:-.297252E-02		

[Table 6] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s4	-13.11538	0.1	
	K:-54.236007 A:-.116656E+00 B:-.143241E+01 C:0.655851E+01 D:0.797153E+02 E:-.477310E-14 F:-.161325E-15		
s5	Infinity	0. 1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A: aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	3.000
WL (Wavelength (nm))	635
Refractivity/Abbe's Number Name of Glass	
FCD1	1.494122/81.6
BACD5	1.587007/61.3
CG	1.533
F (Focal Distance of Overall System)	1.7240
F_1 (Focal Distance of Lens adjacent to Object)	3.753

Fourth Embodiment

An objective lens according to this embodiment is shown in FIG. 50 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCDI) having an Abbe's number vd of 81.6 on the d-line and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 51, astigmatism of the same is shown in FIG. 52 and spherical aberration of the same is shown in FIG. 53. A graph showing the lateral aberration (angle of

view: 0.5 degree) is shown in FIG. 54 and a graph showing the lateral aberration (on the axis) is shown in FIG. 55. The conditions of the design are as shown in Table 7.

[Table 7]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	1.90713	1.572909	FCD1
	K:-0,197701 A:-.651357E-02 B:-.160952E-02 C:-.178084E-03 D:-.123607E-03 E:0.560740E-04 F:-.153752E-04		
s2	-56.67697	0.536935	
	K:-2844.414929 A:0.214002E-02 B:-.604610E-03 C:0.185228E-03 D:-.215933E-04 E:0.120640E-03 F:-.108143E-04		
s3	1.11205	1.351409	BACD5
	K:-0.111875 A:0.734171E-02 B:-.120690E-03 C:0.156026E-01 D:-.300969E-01 E:0.367300E-03 F:-.297252E-02		
s4	-9.43955	0.1	
	K:-963.993459 A:-.25 5448E-01 B:-.203457E+00 C:-.190844E+01 D:0.573442E+02 E:-.477310E-14 F:-.161324E-15		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	3.000

[Table 7] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
WL (Wavelength (nm))		635	
Refractivity/Abbe's Number			
Name of Glass			
FCD 1		1.494122/81.6	
BACD5		1.587007/61.3	
CG		1.533	
F (Focal Distance of Overall System)		1.724	
F_1 (Focal Distance of Lens adjacent to Object)		3.7674	

Fifth Embodiment

An objective lens according to this embodiment is shown in FIG. 56 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (694.532) having an Abbe's number vd of 53.2 on the d-line.

A graph showing distortion of the foregoing objective lens is shown in FIG. 57, astigmatism of the same is shown in FIG. 58 and spherical aberration of the same is shown in FIG. 59. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 60 and a graph showing the lateral aberration (on the axis) is shown in FIG. 61. The conditions of the design are as shown in Table 8.

[Table 8]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.41517	1.922989	694.532
	K:-0.110174 A:-.378893E-02 B:-.541195E-03 C:-.960116E-04 D:-.386475E-04 E:0.280669E-04 F:-.434129E-05		
s2	7.15010	0.437551	
	K:-4.435096 A:0.333331E-02 B:-.512249E-03 C:-.206223E-03 D:-.496133E-03 E:0.663443E-03 F:0.211130E-03		
s3	1.14341	1.283909	694.532
	K:-0.094861 A:0.872481E-02 B:-.149417E-02 C:0.500504E-03 D:-.141032E-01 E:-.117889E-01 F:-.682353E-02		
s4	4.20130	0.2	
	K:-85.005628 A:-.161969E+00 B:-.702663E+00 C:-.814707E+01 D:0.549823E+02 E:0.318668E-16 F:-.315831E-17		
s5	Infinity	0.1	CG

[Table 8] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	2.928
WL (Wavelength (nm))	635
Refractivity/Abbe's Number Name of Glass 694.532 CG	 1.691156/53.2 1.533
F (Focal Distance of Overall System)	1.83
F_1 (Focal Distance of Lens adjacent to Object)	4.5256

Sixth Embodiment

An objective lens according to this embodiment is shown in FIG. 62 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number νd of 81.6 on the d-line.

A graph showing distortion of the foregoing objective lens is shown in FIG. 63, astigmatism of the same is shown in FIG. 64 and spherical aberration of the same is shown in FIG. 65. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 66 and a graph showing the lateral aberration (on the axis) is shown in FIG. 67. The conditions of the design are as shown in Table 9.

[Table 9]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	

[Table 9] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s1	1.20427	1.079421	FCD1
	K:-0.151750 A:-.351418E-01 B:-.170891E-01 C:-.360726E-02 D:0.744766E-03 E:-.170337E-02 F:-,108452E-01		
s2	16.78714	0.196694	
	K:49.948 A:0.930169E-02 B:-.352835E-02 C:0,169634E-01 D:-.293743E-01 E:-.210303E-01 F:0.282409E-01		
s3	0.71596	0.877974	FCD1
	K:-0.158917 A:0.127791E+00 B:-.293900E-01 C:0,152007E+00 D:-.713059E-01 E:-.407821E+01 F:-.421999E-06		
s4	-1.50236	0.1	
	K:-653.584610 A:-.871780E+00 B:-.139204E+01 C:0.142400E+03 D:-.886033E+03 E:0.139585E-12 F:0.139480E-13		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A: aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	2.000
WL (Wavelength (nm))	635
Refractivity/Abbe's Number Name of Glass FCD1	1.494122/81.6

[Table 9] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
CG		1.533	
F (Focal Distance of Overall System)		1.15	
F_1 (Focal Distance of Lens adjacent to Object)		2.5667	

Seventh Embodiment

An objective lens according to this embodiment is shown in FIG. 68 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number νd of 81.6 on the d-line.

A graph showing distortion of the foregoing objective lens is shown in FIG. 69, astigmatism of the same is shown in FIG. 70 and spherical aberration of the same is shown in FIG. 71. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 72 and a graph showing the lateral aberration (on the axis) is shown in FIG. 73. The conditions of the design are as shown in Table 10.

[Table 10]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.78048	2.499596	FCD1
	K:-0.217514 A:-.931418E-03 B:-.254650E-03 C:0.674176E-05 D:-.426555E-05 E:0.0 F:0.0		
s2	-26.70920	0.368815	
	K:-268.285588 A:0.370816E-02 B:-.238371E-03 C:-.249985E-03 D:0.517264E-04 E:0.0 F:0.0		
s3	1.51391	2.137504	FCD1
	K:-0.424397 A:0.141105E-01 B:0.538826E-02 C:0.239631E-02 D:-.448922E-03 E:0.0 F:0.0		
s4	-9.00	0.1	
	K:0.0 A:0.0 B:0.0 C:0.0 D:0.0 E:0.0 F:0.0		
s5	Infinity	0. 1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2/R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

[Table 10] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
X : depth from vertex of surface Y : height from optical axis R : paraxis R K : cone constant A : aspheric coefficient of term Y^4 B : aspheric coefficient of term Y^6 C : aspheric coefficient of term Y^8 D : aspheric coefficient of term Y^{10} E : aspheric coefficient of term Y^{12} F : aspheric coefficient ofterm Y^{14}			
EPD (Diameter of Entrance Pupil (mm))		4.45	
WL (Wavelength (nm))		680	
Refractivity/ Abbe's Number Name of Glass FCD1 CG		 1494122/81 6 1.5769	
F (Focal Distance of Overall System)		2.5	
F_1 (Focal Distance of Lens adjacent to Object)		5.2551	

Eighth Embodiment

An objective lens according to this embodiment is shown in FIG. 74 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number νd of 81.6 on the d-line and optical glass (BACD5) having an Abbe's number νd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 75, astigmatism of the same is shown in FIG. 76 and spherical aberration of the same is shown in FIG. 77. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 78 and a graph showing the lateral aberration (on the axis) is shown in FIG. 79. The conditions of the design are as shown in Table 11. The objective lens according to this embodiment is an objective lens satisfying the ranges of the diameter of the beam, the working distance (WD) and the NA shown in FIGS. 22 and 24, the objective lens according to this embodiment corresponding to point 2 shown in FIG. 22.

[Table 11]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	

[Table 11] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s1	2.46928	1.176806	FCD1
	K:-0.093789 A:-.335472E-02 B:0.152884E-03 C:0.707504E-04 D:0.148633E-04 E:0.553064E-05 F:-.174217E-05		
s2	316.20027	0.020092	
	K:51211.981179 A:0.773695E-02 B:0.147280E-02 C:0.290309E-03 D:-.124348E-04 E:-.831848E-04 F:0.271640E-04		
s3	1.33699	1.198996	BACD5
	K:-0.092429 A:-.706457E-03 B:0.219957E-03 C:-.209120E-02 D-.411553E-03 E:0.133140E-02 F:-.164287E-02		
s4	2.58980	0.8	
	K:-8.513851 A:-.196541E-01 B:-.252808E-01 C:0.649868E-02 D:0,166035E-01 E:-.920880E-02 F:0.328621E-10		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	3.000
WL (Wavelength (nm))	635
Refractivity/Abbe's Number Name of Glass FCD1	1.494122/81.6

[Table 11] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
BACD5		1.587007/61.3	
CG		1.533	
F (Focal Distance of Overall System)		2.1100	
F_1 (Focal Distance of Lens adjacent to Object)		5.0304	

Ninth Embodiment

An objective lens according to this embodiment is shown in FIG. 80 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCDI) having an Abbe's number vd of 81.6 on the d-line and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 81, astigmatism of the same is shown in FIG. 82 and spherical aberration of the same is shown in FIG. 83. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 84 and a graph showing the lateral aberration (on the axis) is shown in FIG. 85. The conditions of the design are as shown in Table 12. The objective lens according to this embodiment is an objective lens satisfying the ranges of the diameter of the beam, the working distance (WD) and the NA shown in FIGS. 22 and 24, the objective lens according to this embodiment corresponding to point 3 shown in FIG. 22.

[Table 12]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	0.95940	0.292788	FCD1
	K:-0.230993 A:-.67862E-01 B:0.140833E+00 C:0.348581E-01 D:-.149134E+01 E:-.327087E+01 F:0.954103E-01		
s2	2.80442	0.0	
	K:-7.470389 A:0.164931E+00 B:0.166114E+00 C:0.579542E+00 D:-.747670E+01 E:-.417068E+02 F:0.170241E+03		
s3	0.46942	0.407387	BACD5
	K:-0.133476 A:-.122398E+00 B:-.254028E+00 C:-.363976E+01 D:-.253712E+02 E:0.828936E+01 F:-.515431E+03		
s4	5.03874	0.30	
	K:-1188.332634 A:0.454966E+00 B:0.304699E+00 C:-.632742E+02 D:0.477110E+03 E:-.584725E+03 F:-.295638E+04		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

[Table 12] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y / R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	1.000
WL (Wavelength (nm))	635
Refractivity/Abbe's Number Name of Glass	
FCD1	1.494122/81.6
BACD5	1.587007/61.3
CG	1.5769
F (Focal Distance of Overall System)	0.704
F_1 (Focal Distance of Lens adjacent to Object)	2.8041

Tenth Embodiment

An objective lens according to this embodiment is shown in FIG. 86 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number vd on the d-line of 81.3 and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 87, astigmatism of the same is shown in FIG. 88 and spherical aberration of the same is shown in FIG. 89. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 90 and a graph showing the lateral aberration (on the axis) is shown in FIG. 91. The conditions of the design are as shown in Table 13. The objective lens according to this embodiment is an objective lens satisfying the ranges of the diameter of the beam, the working distance (WD) and the NA shown in FIGS. 22 and 24, the objective lens according to this embodiment corresponding to point 9 shown in FIG. 24.

[Table 13]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	

[Table 13] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
s1	1.97265	1.666846	FCD1
	K:-0.136564 A:-.102065E-01 B:-.105703E-02 C:-.205627E-03 D:-.102022E-03 E:-.167207E-04 F:-.847017E-05		
s2	101.83827	0.438961	
	K:3327.215080 A:0.237871E-03 B:-.106925E-02 C:-.509674E-03 D:-.431489E-03 E:0.166565E-03 F:0.843038E-05		
s3	1.11740	1.513776	BACD5
	K:-0.065262 A:0.329554E-01 B:-.147812E-01 C:0.299582E-01 D:-.165416E-01 E:-.161770E-01 F:0.177083E-01		
s4	-1.09291	0.05	
	K:-860.033414 A:0.540356E+00 B:0.690883E+01 C:0.445748E+03 D:-.100405E+05 E:0.842897E-21 F:-.149771E-21		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A : aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient of term Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	3.000
WL (Wavelength (nm))	635
Refractivity/ Abbe's Number Name of Glass	

[Table 13] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
FCD 1		1.494122/81.6	
BACD5		1.587007/61.3	
CG		1.533	
F (Focal Distance of Overall System)		1.65	
F_1 (Focal Distance of Lens adjacent to Object)		4.0487	

Eleventh Embodiment

An objective lens according to this embodiment is shown in FIG. 92 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCDI) having an Abbe's number vd on the d-line of 81.6 and optical glass (BK7) having an Abbe's number vd of 64.1.

A graph showing distortion of the foregoing objective lens is shown in FIG. 93, astigmatism of the same is shown in FIG. 94 and spherical aberration of the same is shown in FIG. 95. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 96 and a graph showing the lateral aberration (on the axis) is shown in FIG. 97. The conditions of the design are as shown in Table 14.

[Table 14]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.46917	3.042666	FCD1
	K:-0.177274 A:-.353215E-02 B:-.452433E-03 C:-.556160E-05 D:-.991159E-05 E:-.128023E-07 F:-.159371E-06		
s2	-12.58525	0.491772	
	K:-13.032252 A:0.307368E-02 B:0.799138E-04 C:0.242782E-03 D:-.981829E-04 E:-.324027E-04 F:0.162258E-04		
s3	1.25000	1.481326	BK7
	K:0.0 A:0.0 B:0.0 C:0.0 D:0.0 E:0.0 F:0.0		
s4	Infinity	0.30	
	K:0.0 A:0.0 B:0.0 C:0.0 D:0.0 E:0.0 F:0.0		
s5	Infinity	0. 1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	

[Table 14] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
Equation of Aspheric Surface $$X=\frac{Y^2/R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}}+AY^4+BY^6+CY^8+DY^{10}+EY^{12}+FY^{14}$$ X : depth from vertex of surface Y : height from optical axis R : paraxis R K : cone constant A : aspheric coefficient of term Y^4 B : aspheric coefficient of term Y^6 C : aspheric coefficient of term Y^8 D : aspheric coefficient of term Y^{10} E : aspheric coefficient of term Y^{12} F : aspheric coefficient of term Y^{14}			
EPD (Diameter of Entrance Pupil (mm))	3.7894		
WL (Wavelength (nm))	635		
Refractivity/Abbe's Number Name of Glass FCD1 BACD5 CG	 1.494122/81.6 1.515014 1.533		
F (Focal Distance of Overall System)	2.3684		
F_1 (Focal Distance of Lens adjacent to Object)	4.4767		

Twelfth Embodiment

An objective lens according to this embodiment is shown in FIG. 98 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number νd on the d-line of 81.6 and optical glass (BK7) having an Abbe's number νd of 64.1.

A graph showing distortion of the foregoing objective lens is shown in FIG. 99, astigmatism of the same is shown in FIG. 100 and spherical aberration of the same is shown in FIG. 101. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 102 and a graph showing the lateral aberration (on the axis) is shown in FIG. 103. The conditions of the design are as shown in Table 15.

[Table 15]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	

[Table 15] (continued)

Surface	RDY (Curvature Radius)			THI (Thickness)	GLA (Name of Glass)
s1	2.42115			2.6000	FCD1
	K:-0.346742 A:-.244830E-02 B:-.285636E-03 C:-.146599E-04 D:-.503982E-05 E:0.0 F:0.0				
s2	-13.23414			0.946290	
	K:23.517622 A:0.319611E-02 B:0.260898E-03 C:-.104377E-03 D:0.264903E-04 E:0.0 F:0.0				
s3		1.25		1.4	BK7
	K:0.0 A:0.0 D:0.0	B:0.0 E:0.0	C:0.0 F:0.0		
s4	Infinity			0.075	
	K:0.0 A:0.0 D:0.0	B:0.0 E:0.0	C:0.0 F:0.0		
s5	Infinity			0.1	CG
s6	Infinity			0.0	
IMG	Infinity			0.0	

Equation of Aspheric Surface

$$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$$

X : depth from vertex of surface

Y : height from optical axis

R : paraxis R

K : cone constant

A: aspheric coefficient of term Y^4

B : aspheric coefficient of term Y^6

C : aspheric coefficient of term Y^8

D : aspheric coefficient ofterm Y^{10}

E : aspheric coefficient of term Y^{12}

F : aspheric coefficient of term Y^{14}

EPD (Diameter of Entrance Pupil (mm))	3.9571
WL (Wavelength (nm))	680
Refractivity/Abbe's Number Name of Glass FCD1	1.493009/81.6

[Table 15] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
BACD5		1.513615/64.1	
CG		1.5769	
F (Focal Distance of Overall System)		2.4732	
F_1 (Focal Distance of Lens adjacent to Object)		4.3923	

Thirteenth Embodiment

An objective lens according to this embodiment is shown in FIG. 104 and has a structure in which the lenses 3 and 4 are manufactured by optical glass (FCD1) having an Abbe's number vd of 81.3 on the d-line and optical glass (BACD5) having an Abbe's number vd of 61.3.

A graph showing distortion of the foregoing objective lens is shown in FIG. 105, astigmatism of the same is shown in FIG. 106 and spherical aberration of the same is shown in FIG. 107. A graph showing the lateral aberration (angle of view: 0.5 degree) is shown in FIG. 108 and a graph showing the lateral aberration (on the axis) is shown in FIG. 109. The conditions of the design are as shown in Table 16.

[Table 16]

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
OBJ	Infinity	Infinity	
STO	Infinity	0.0	
s1	2.87688	2.571836	FCD1
	K:-0.101486 A:-.199167E-02 B:-.236129E-03 C:-.317683E-04 D:-.174187E-06 E:-.824255E-06 F:0.0		
s2	30.59199	0.450272	
	K:94.410598 A:0.151777E-02 B:-.507697E-04 C:-.650070E-04 D:-.178174E-04 E:0.425677E-05 F:0.0		
s3	1.665155	2.046516	BACD5
	K:-0.196808 A:0.281473E-02 B:0.168084E-02 C:-.205195E-03 D:0.402182E-03 E:-.867889E-04 F:0.0		
s4	14.89061	0.3	
	K:0.0 A:0.0 B:0.0 C:0.0 D:0.0 E:0.0 F:0.0		
s5	Infinity	0.1	CG
s6	Infinity	0.0	
IMG	Infinity	0.0	
Equation of Aspheric Surface			

[Table 16] (continued)

Surface	RDY (Curvature Radius)	THI (Thickness)	GLA (Name of Glass)
$X = \frac{Y^2 / R}{1+\{1-(1+K)(Y/R)^2\}^{1/2}} + AY^4 + BY^6 + CY^8 + DY^{10} + EY^{12} + FY^{14}$ X : depth from vertex of surface Y : height from optical axis R : paraxis R K : cone constant A : aspheric coefficient of term Y^4 B : aspheric coefficient of term Y^6 C : aspheric coefficient of term Y^8 D : aspheric coefficient of term Y^{10} E : aspheric coefficient of term Y^{12} F : aspheric coefficient of term Y^{14}			
EPD (Diameter of Entrance Pupil (mm))		4.5	
WL (Wavelength (nm))		635	
Refractivity/Abbe's Number Name of Glass FCD1 BACD5 CG		 1.494122/81.6 1.587007/61.3 1.533	
F (Focal Distance of Overall System)		2.647	
F_1 (Focal Distance of Lens adjacent to Object)		6.235	

As described above, the present invention is structured such that the objective lens having a numerical aperture (NA) of 0.7 is realised by a doublet lens including an aspheric surface and the optical pickup apparatus comprises the foregoing objective lens so that an optical recording medium exhibiting a high information recording density is used practically.

That is, the objective lens according to the present invention is made of optical glass having the Abbe's number of 40 or more so that chromatic aberration is prevented even if the NA is enlarged. If a semiconductor laser is employed as the light source, the tolerance for the change in the wavelength of the semiconductor laser can be enlarged and thus the manufacturing yield can be improved.

Since the objective lens according to preferred embodiments of the present invention is structured such that the refractivity of the lens component having a sharper curvature is raised, the curvature can be made to be gentle and the lens can easily be manufactured.

Since the objective lens according to preferred embodiments of the present invention is structured such that the diameter of the beam, the NA and the working distance are limited, the size of the optical pickup apparatus can be reduced, the focal distance can be shortened and the lens having a high NA can easily be manufactured. Since the objective lens according to preferred embodiments of the present invention has a small size, the size of the biaxial actuator for moving the objective lens can be reduced.

Since the objective lens according to preferred embodiments of the present invention has the proper focal distance, the power distribution of the two lens element can be performed optimally. Thus, each lens element can easily be manufactured and the performance of the same can easily be improved, thus resulting in a satisfactory manufacturing

yield.

That is, preferred embodiments of the present invention provide an objective lens which is capable of satisfactorily correcting the chromatic aberration although it has a sufficiently large numerical aperture (NA), the weight of which can be reduced and which can easily be manufactured.

The optical pickup apparatus according to the present invention, having the above-mentioned objective lens and adapted to the optical recording medium comprising the transparent substrate, the thickness of which is specified, is able to correct coma-aberration. As a result, the optical recording medium can easily be manufactured.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form can be changed in the details of construction and in the combination and arrangement of parts without departing from the scope of the invention as hereinafter claimed.

Claims

1. An objective lens comprising two lens elements (3, 4) made of optical glass having an Abbe's number of 40 or greater on a d-line and having a doublet structure, wherein at least either surface is formed into an aspheric surface and the numerical aperture is 0.7 or more.

2. An objective lens according to claim 1, wherein the Abbe's number of the optical glass forming the two lens elements (3, 4) on the d-line is 60 or greater and the numerical aperture is made to be 0.8 or more.

3. An objective lens according to claim 1 or 2, wherein when an assumption is made that the refractivity of optical glass for forming the one (4) of the lens elements in which an angle made between a tangential plane of a plane in the periphery of the lens element and a plane perpendicular to an optical axis is larger than the angle of the other lens element (3) is n_1, and the refractivity of the optical glass forming the other lens element (3) is n2, the following relationship is satisfied

$$n_1 > n_2.$$

4. An objective lens according to claim 1, 2 or 3, wherein when an assumption is made that the diameter of an incidental laser beam is BW, the working distance is WD and the numerical aperture is NA, the following relationships are satisfied:

$$\text{if } 1.0 \leq BW < 4.5,\ 0.05 \leq WD \text{ and } 0.7 \leq NA < 0.8,$$

then

$$WD \leq 0.25676BW + 0.039189,$$

$$\text{if } 0.8 \leq NA < 0.9, \text{ then } WD \leq 0.14054BW - 0.064865,$$

and

$$\text{if } 0.9 \leq NA, \text{ then } WD \leq 0.096429BW - 0.244640.$$

5. An objective lens according to any previous claim, wherein the ratio F_1/F of the focal distance F_1 of the lens (3) disposed on the side on which a light beam is made incident and the focal distance F of the overall system of the lens satisfies the following relationship:

$$1.7 < (F_1/F) < 2.5.$$

6. An objective lens according to any previous claim, wherein the aberration of said objective lens is corrected to

correspond to thickness T of a transparent substrate (5) of an optical recording medium disposed on a signal recording surface (12) and supporting said signal recording surface and said objective lens satisfies the following relationships:

$$\text{if } 0.7 \leq \text{NA (the numerical aperture)} < 0.8, \text{ then } T \leq 0\ 32 \text{ mm},$$

$$\text{if } 0.8 \leq \text{NA} < 0.9, \text{ then } T \leq 0.20 \text{ mm},$$

and

$$\text{if } 0.9 \leq \text{NA}, \text{ then } T \leq 0.11 \text{ mm}.$$

7. An optical pickup apparatus comprising:

   a light source; and
   an objective lens (3, 4) for converging a laser beam emitted from said light source onto a signal recording surface (12) of an optical recording medium, wherein said lens has two lens elements (3, 4) made of optical glass having an Abbe's number of 40 or greater on a d-line and having a doublet structure, at least either surface is formed into an aspheric surface and the numerical aperture is 0.7 or more.

8. An optical pickup apparatus according to claim 7, wherein the Abbe's number of the optical glass forming the two lens elements on the d-line is 60 or greater and the numerical aperture is made to be 0.8 or more.

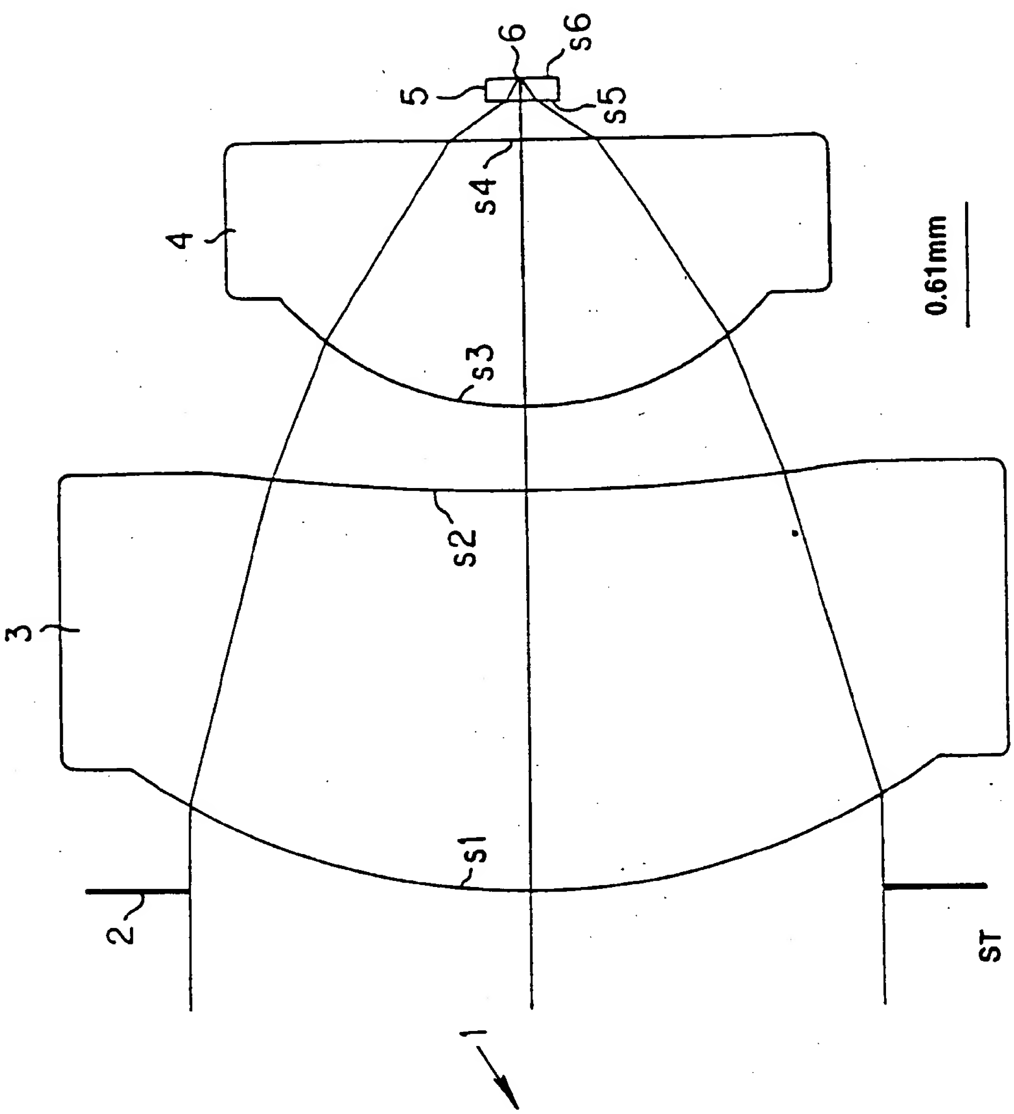
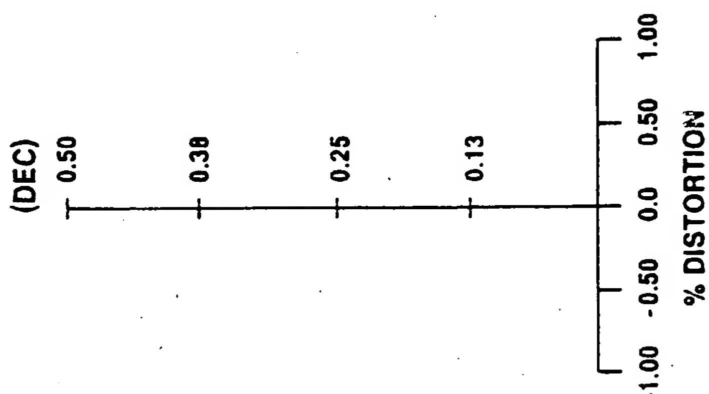
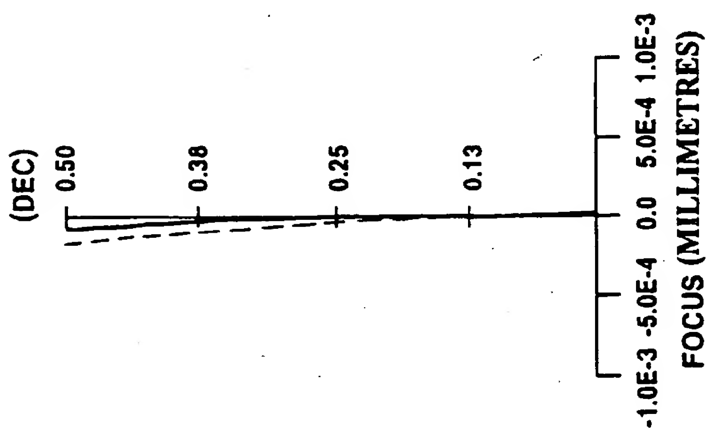


FIG.1



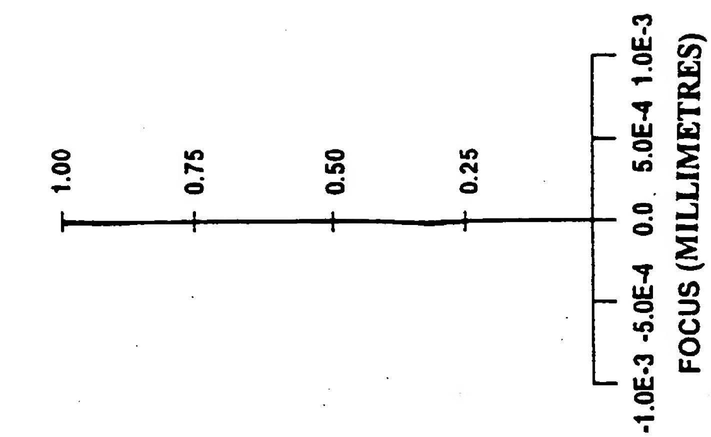
DISTORTION

FIG.2



ASTIGMATIC
FIELD CURVES

FIG.3



LONGITUDINAL
SPHERICAL ABER

FIG.4

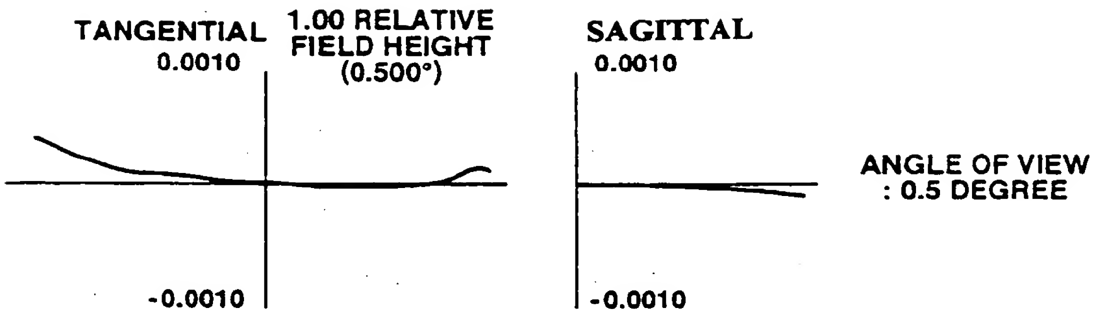

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
0.0010
-0.0010
SAGITTAL
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.5

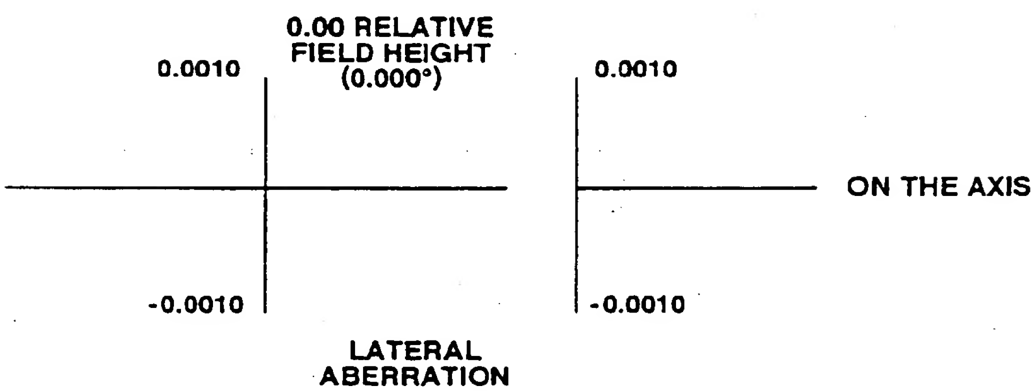

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.6

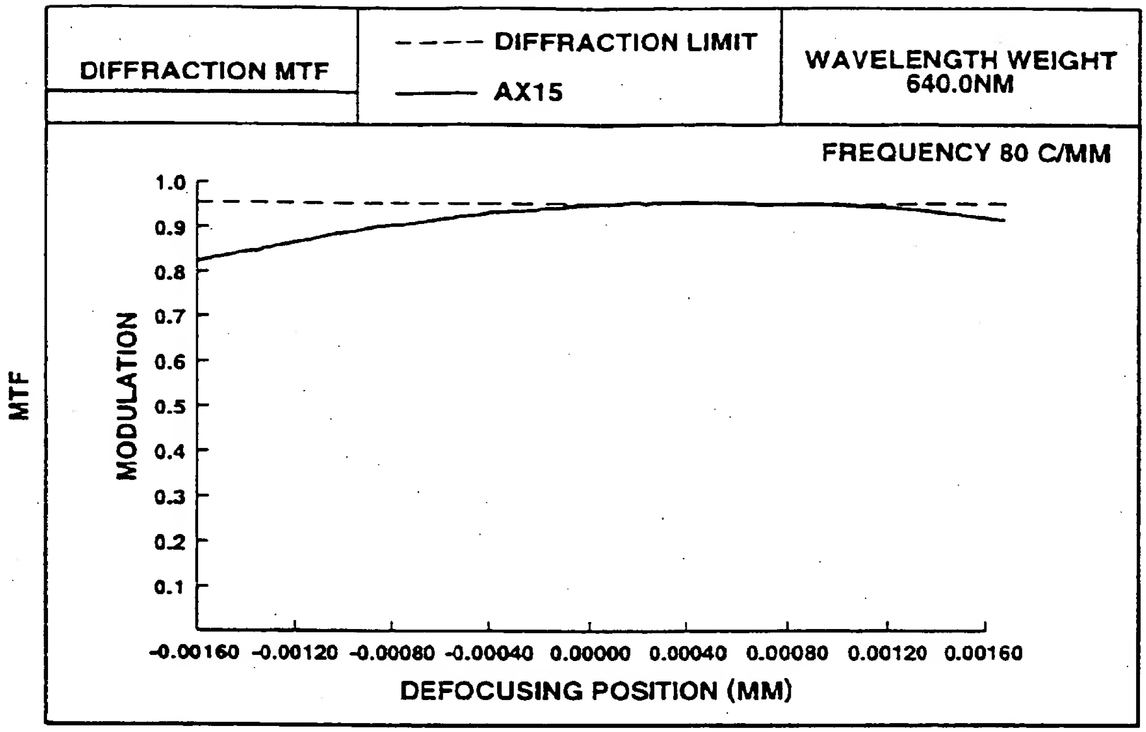

DIFFRACTION MTF
DIFFRACTION LIMIT
AX15
WAVELENGTH WEIGHT
640.0NM
FREQUENCY 80 C/MM
MTF
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.00160 -0.00120 -0.00080 -0.00040 0.00000 0.00040 0.00080 0.00120 0.00160
DEFOCUSING POSITION (MM)

FIG.7

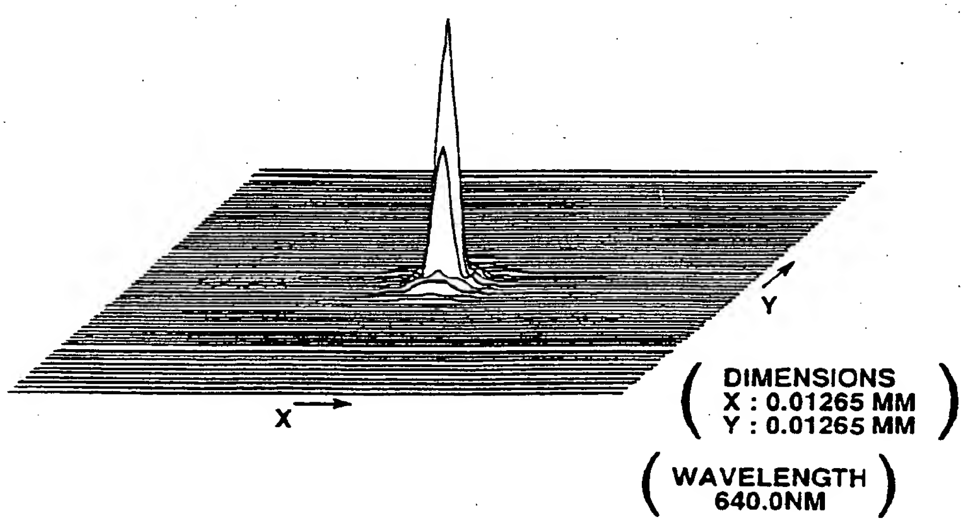

Y
X
DIMENSIONS
X : 0.01265 MM
Y : 0.01265 MM
WAVELENGTH
640.0NM

FIG.8

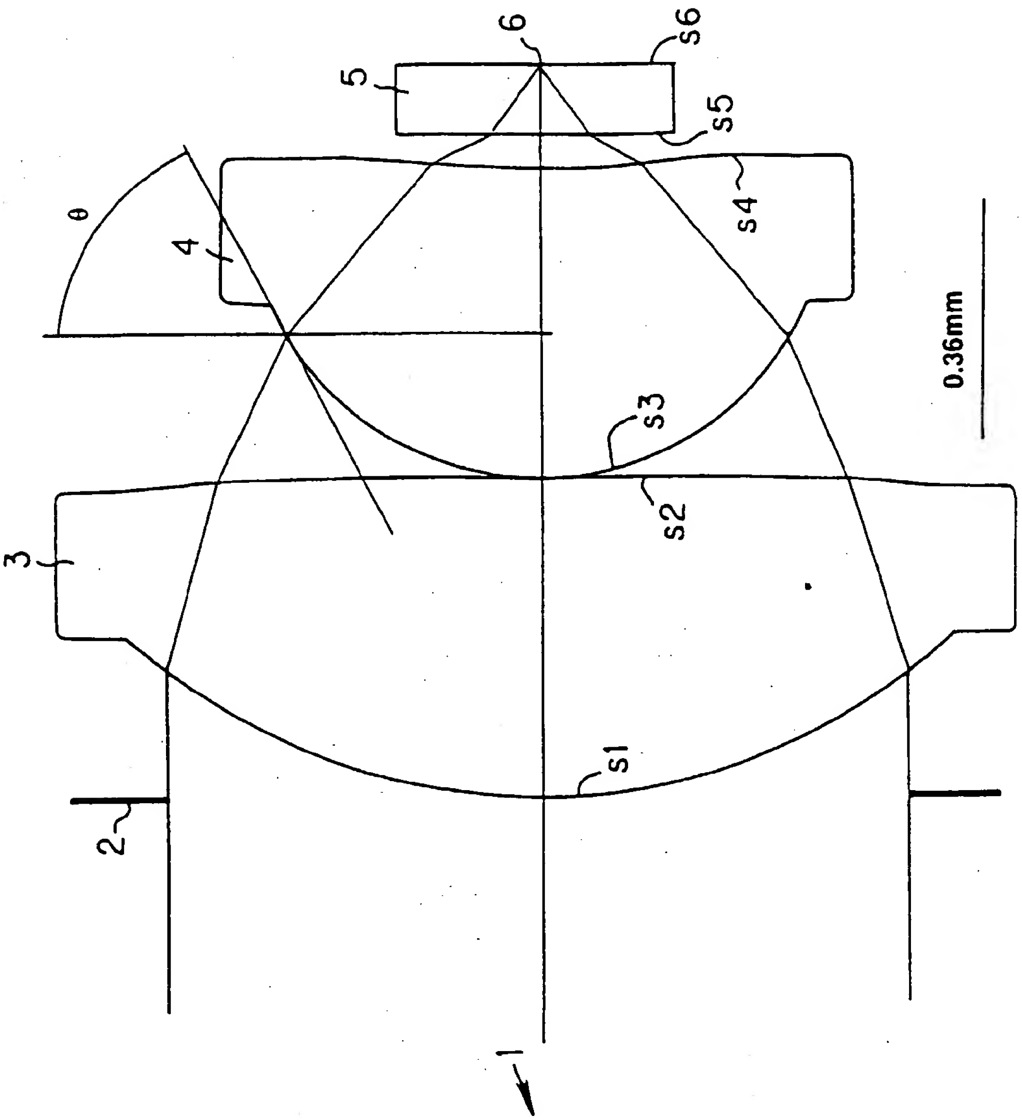
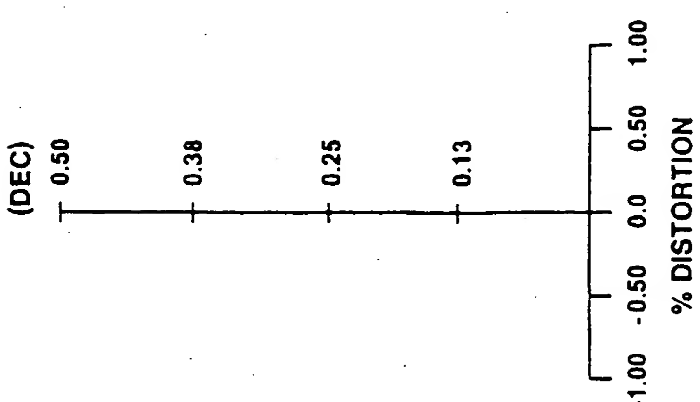
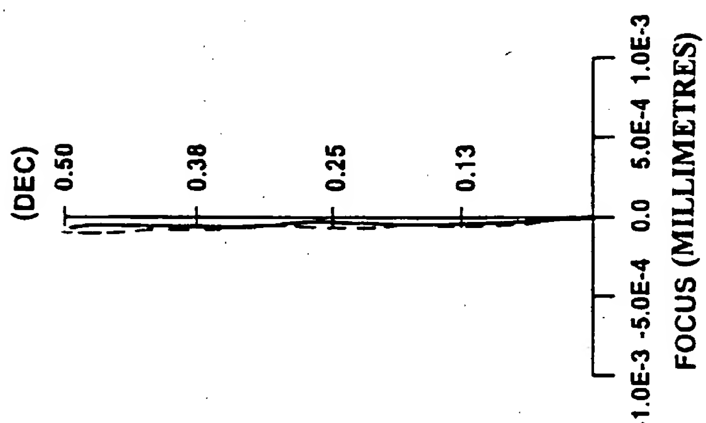


FIG.9



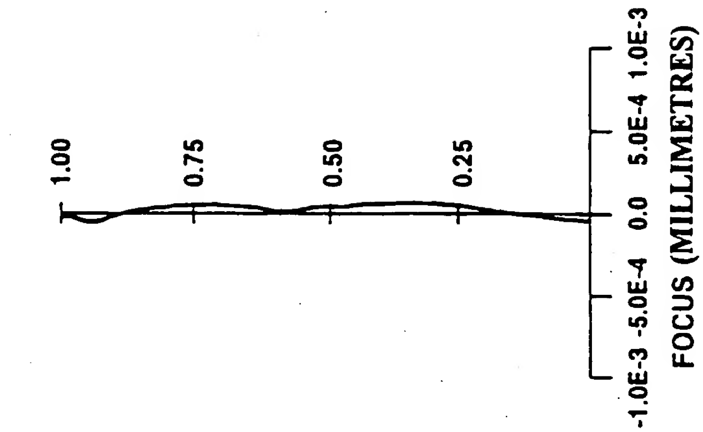
DISTORTION

FIG.10



ASTIGMATIC
FIELD CURVES

FIG.11



LONGITUDINAL
SPHERICAL ABER

FIG.12

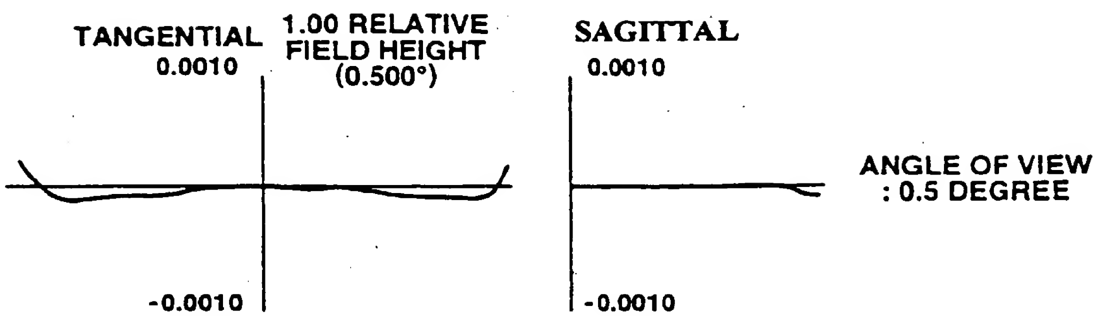

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
0.0010
-0.0010
SAGITTAL
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.13

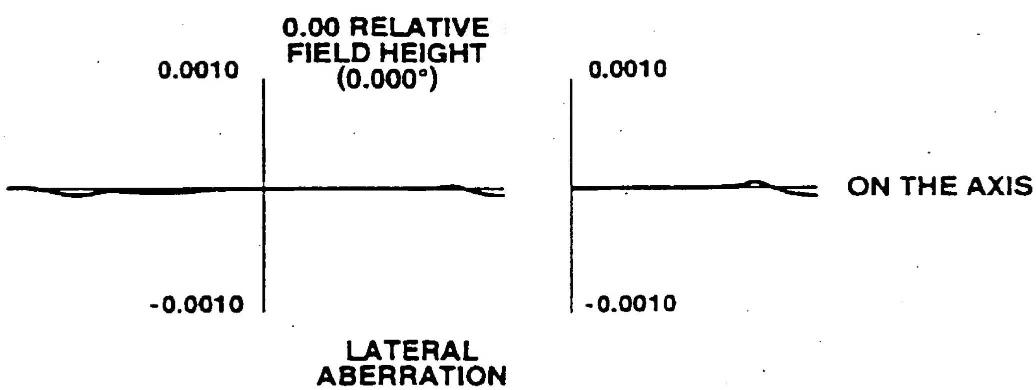

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.14

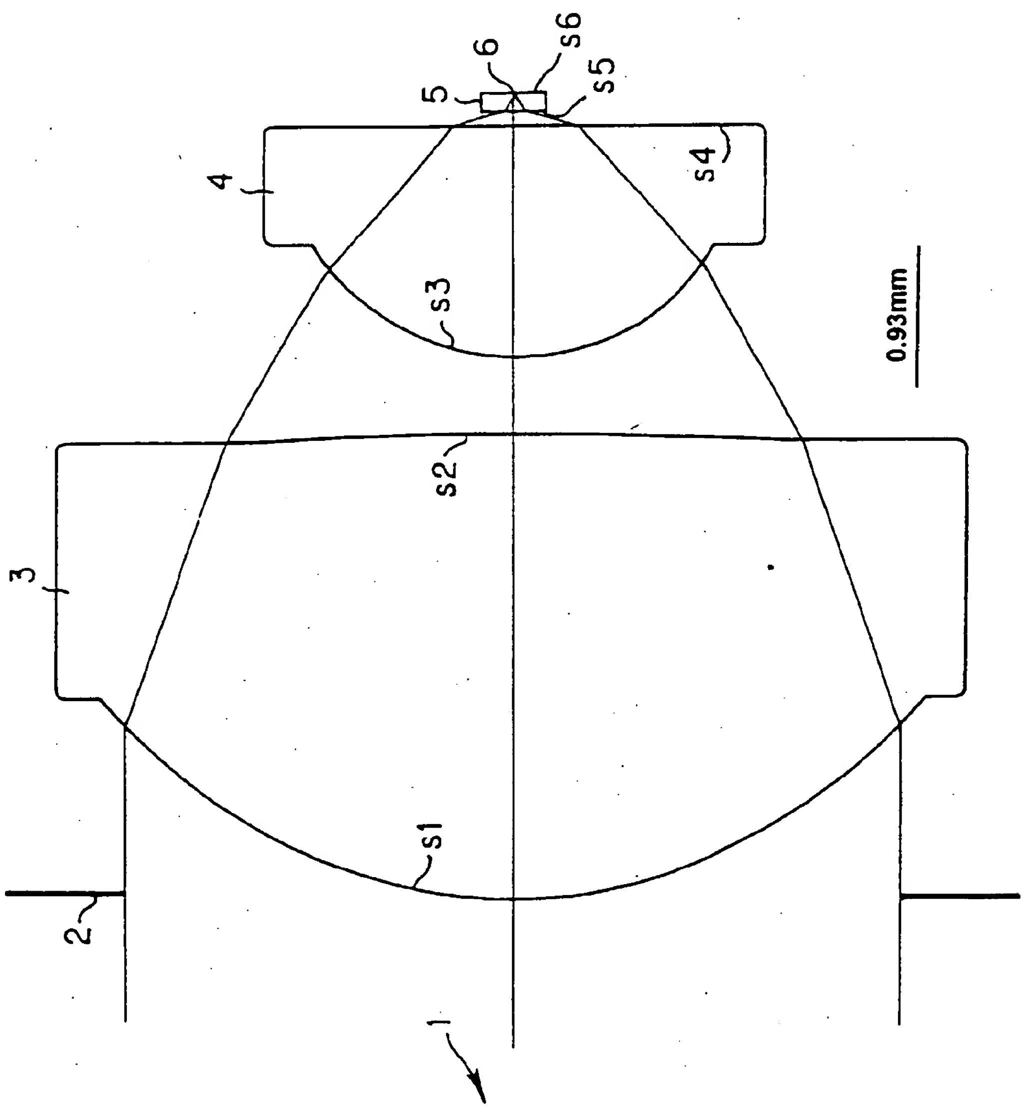
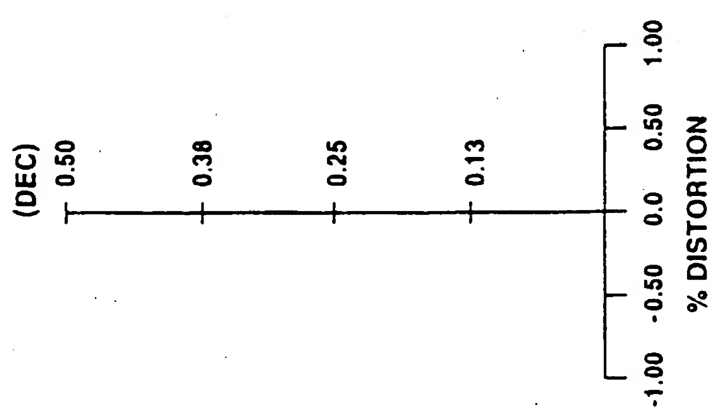
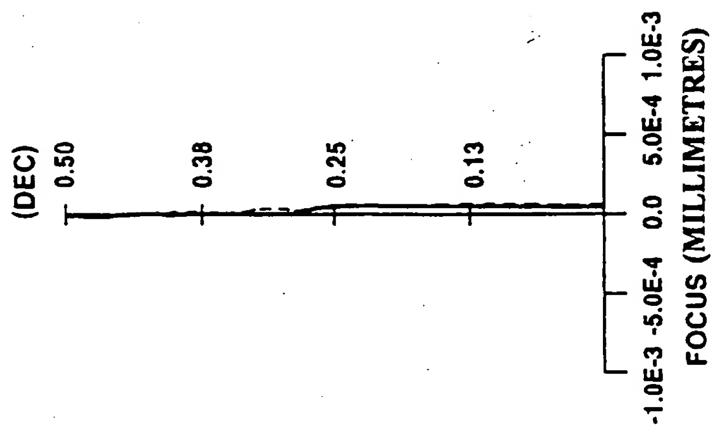


FIG.15



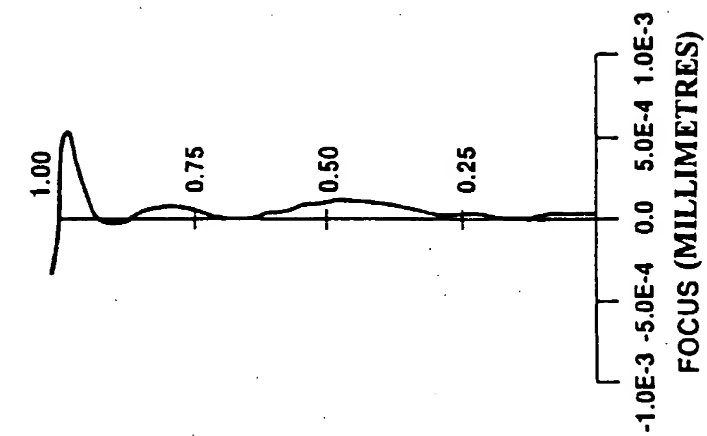
DISTORTION

FIG.16



ASTIGMATIC FIELD CURVES

FIG.17



LONGITUDINAL SPHERICAL ABER

FIG.18

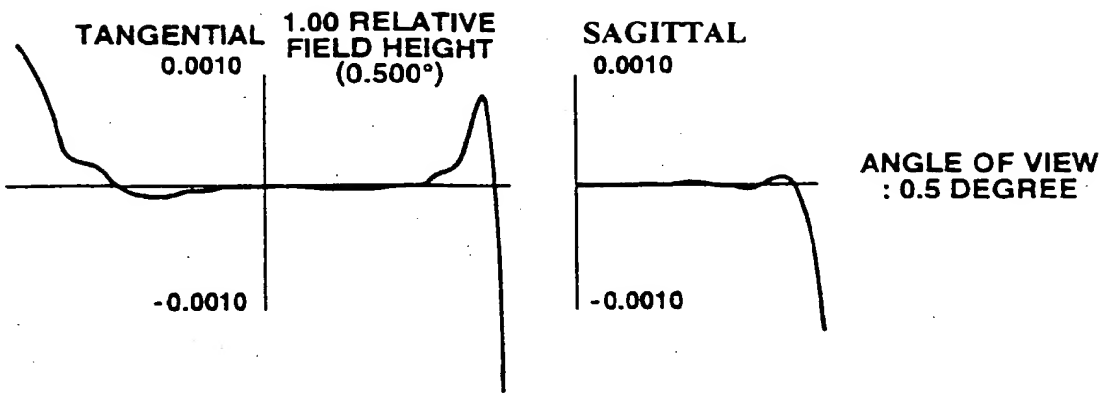

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
-0.0010
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.19

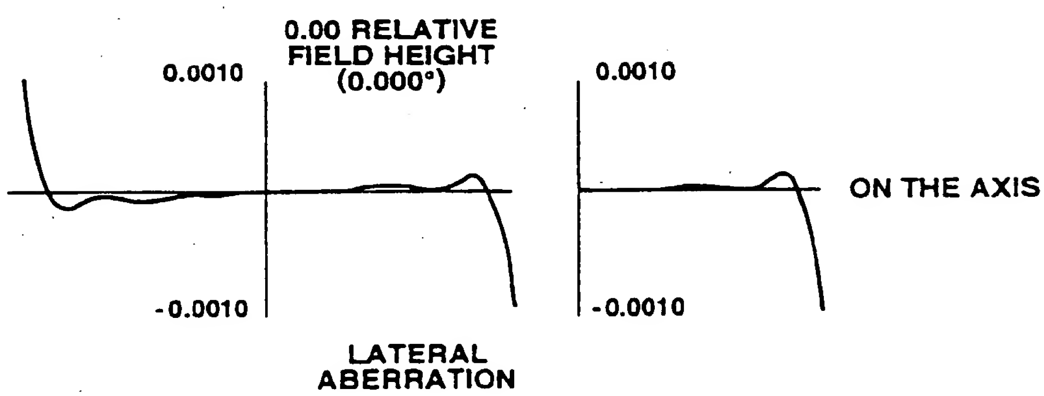

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.20

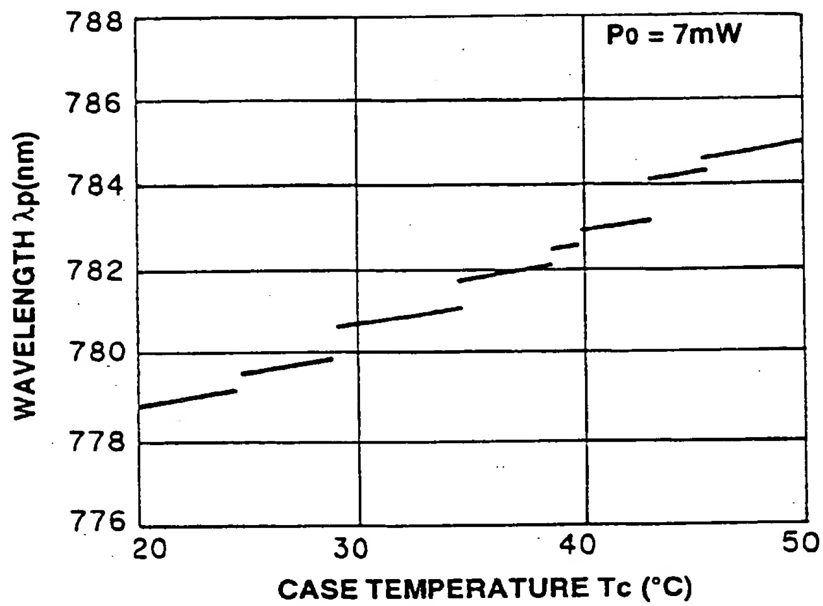

Po = 7mW
788
786
784
782
780
778
776
WAVELENGTH λp(nm)
20
30
40
50
CASE TEMPERATURE Tc (°C)

FIG.21

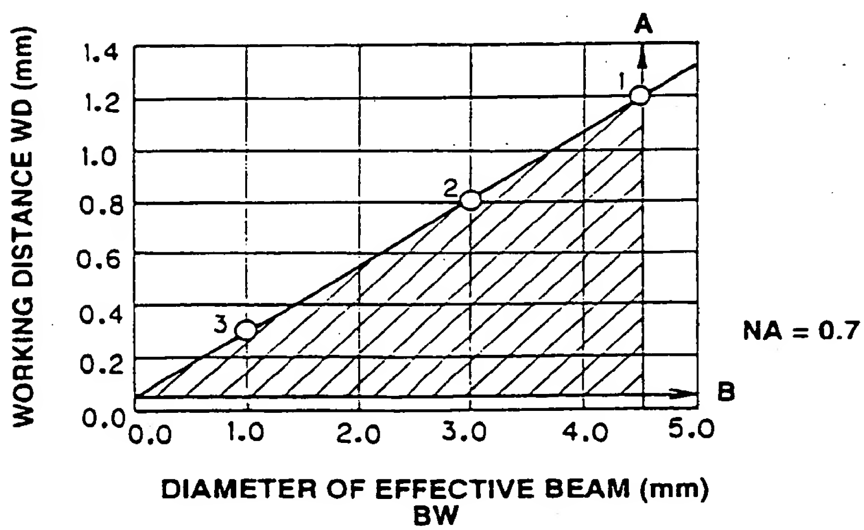
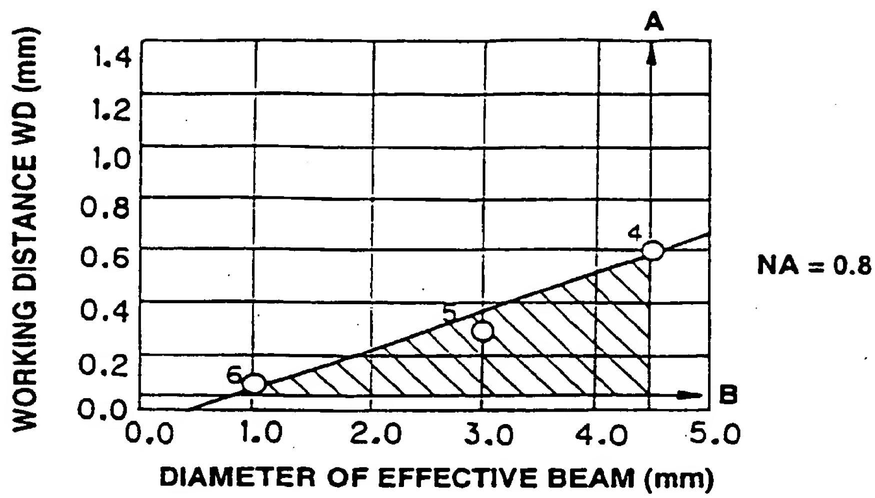
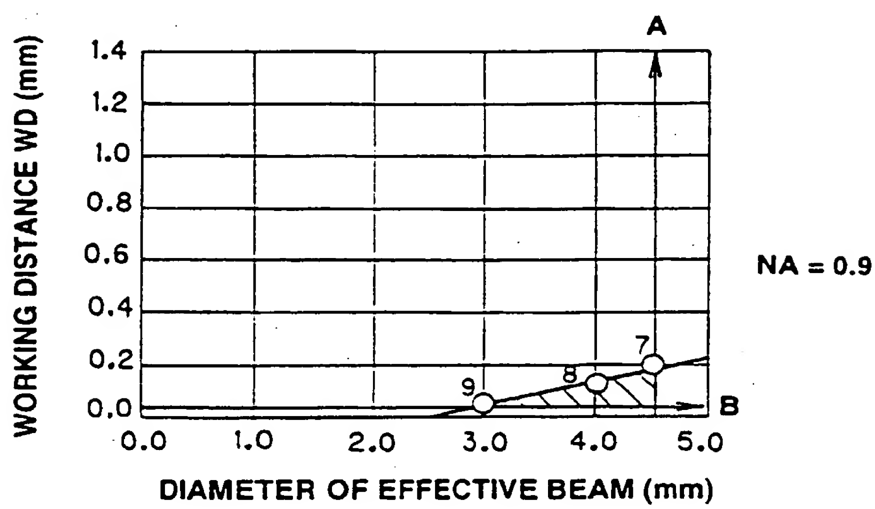

A
1
2
3
B
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
WORKING DISTANCE WD (mm)
0.0
1.0
2.0
3.0
4.0
5.0
NA = 0.7
DIAMETER OF EFFECTIVE BEAM (mm)
BW

FIG.22



WORKING DISTANCE WD (mm)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
B
4
5
6
0.0
1.0
2.0
3.0
4.0
5.0
DIAMETER OF EFFECTIVE BEAM (mm)
NA = 0.8

FIG.23



WORKING DISTANCE WD (mm)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
B
7
8
9
0.0
1.0
2.0
3.0
4.0
5.0
DIAMETER OF EFFECTIVE BEAM (mm)
NA = 0.9

FIG.24

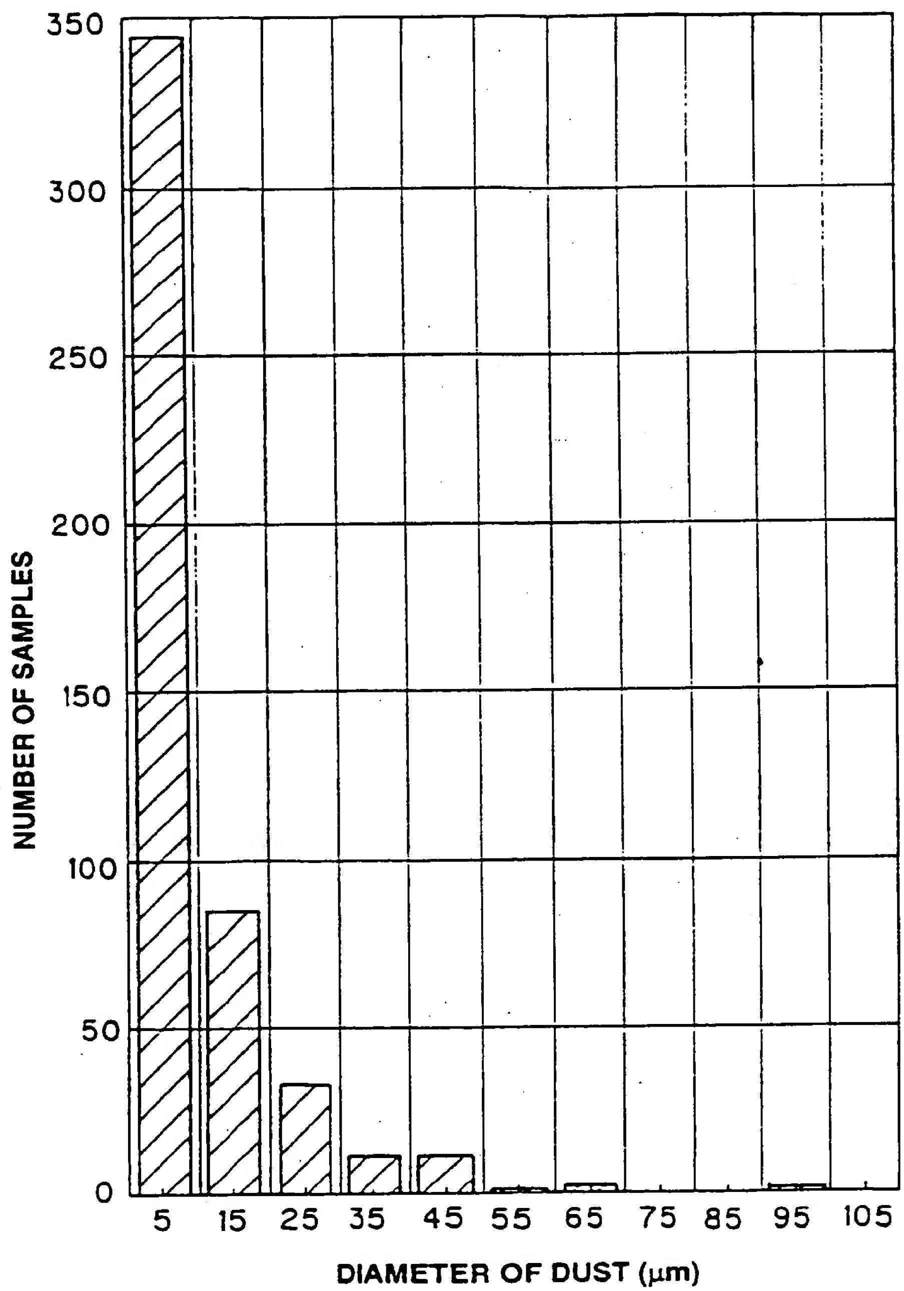

350
300
250
200
150
100
50
0
NUMBER OF SAMPLES
5
15
25
35
45
55
65
75
85
95
105
DIAMETER OF DUST (μm)

FIG.25

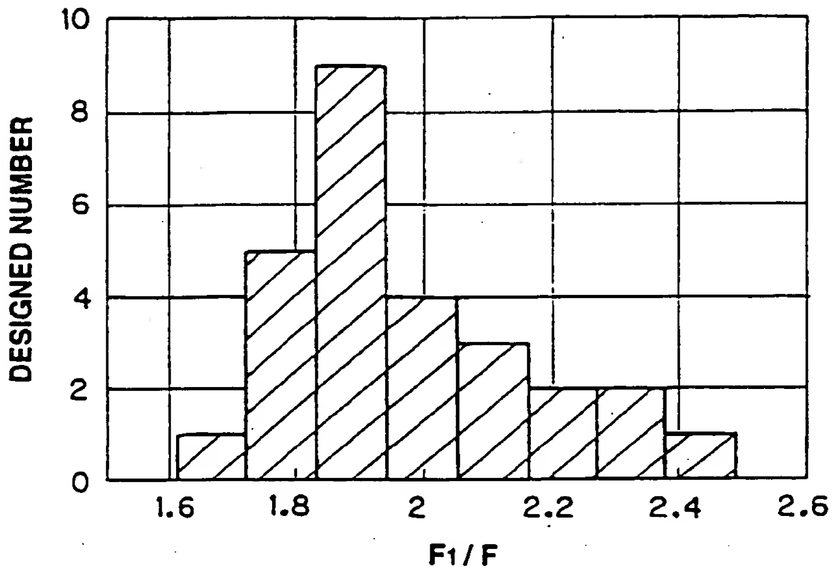


FIG.26

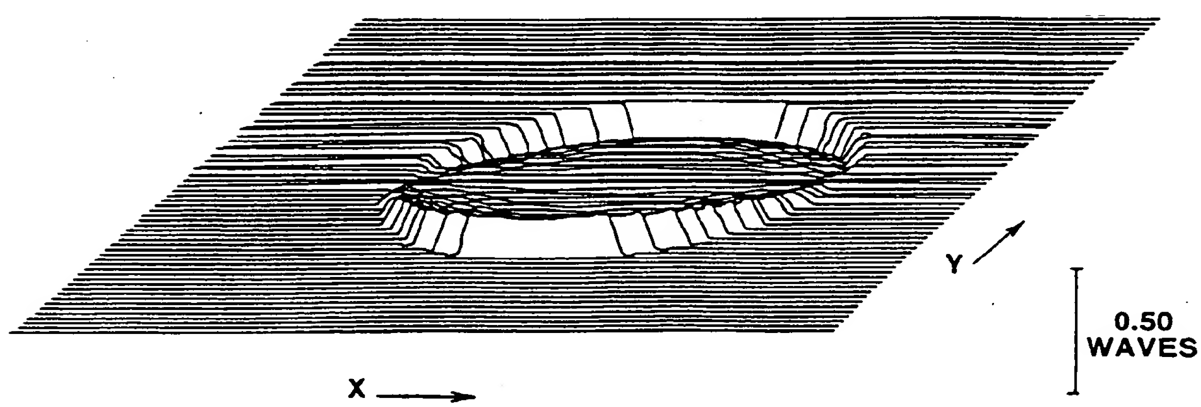


FIG.27

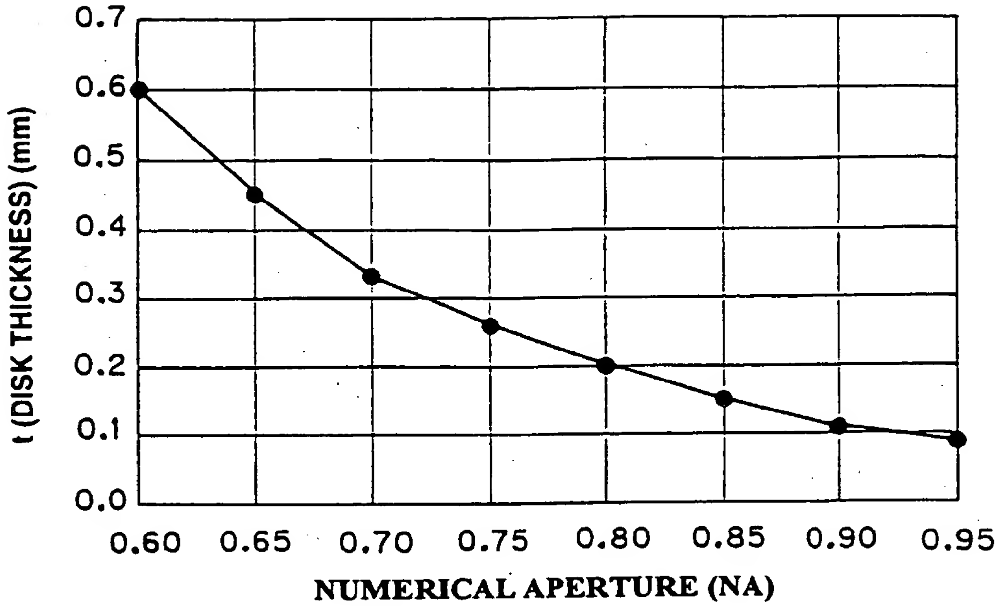

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
t (DISK THICKNESS) (mm)
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
NUMERICAL APERTURE (NA)

FIG.28

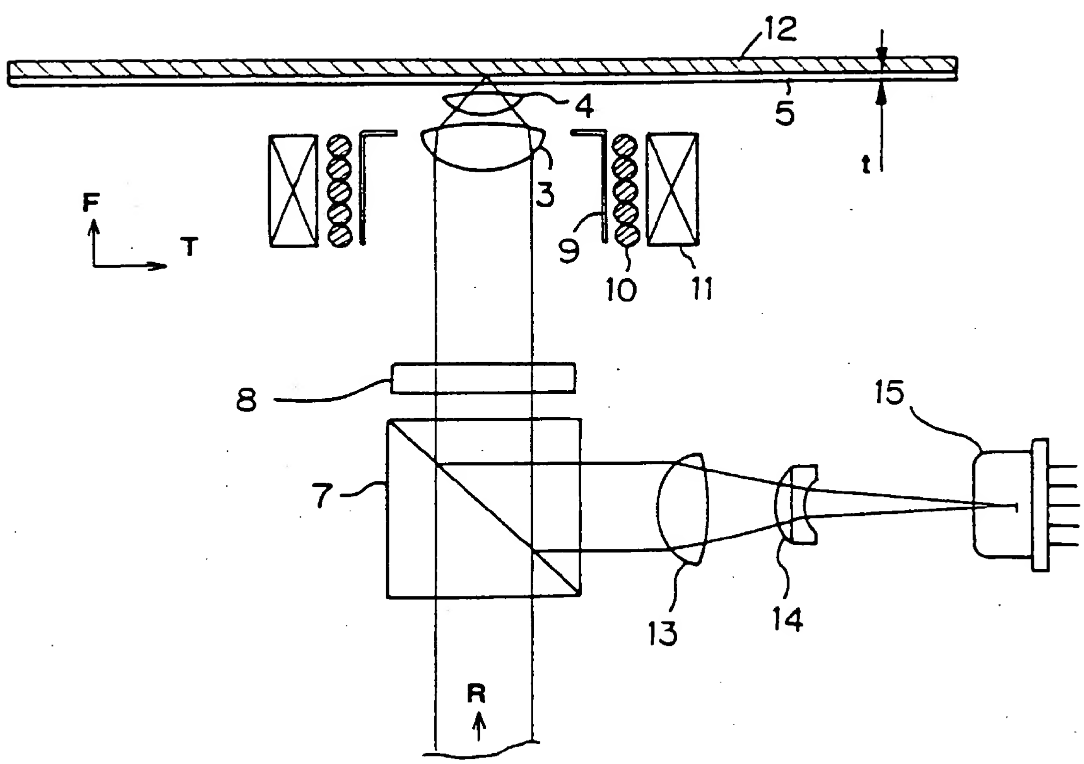

12
4
5
t
3
F
T
9
10
11
8
15
7
13
14
R

FIG.29

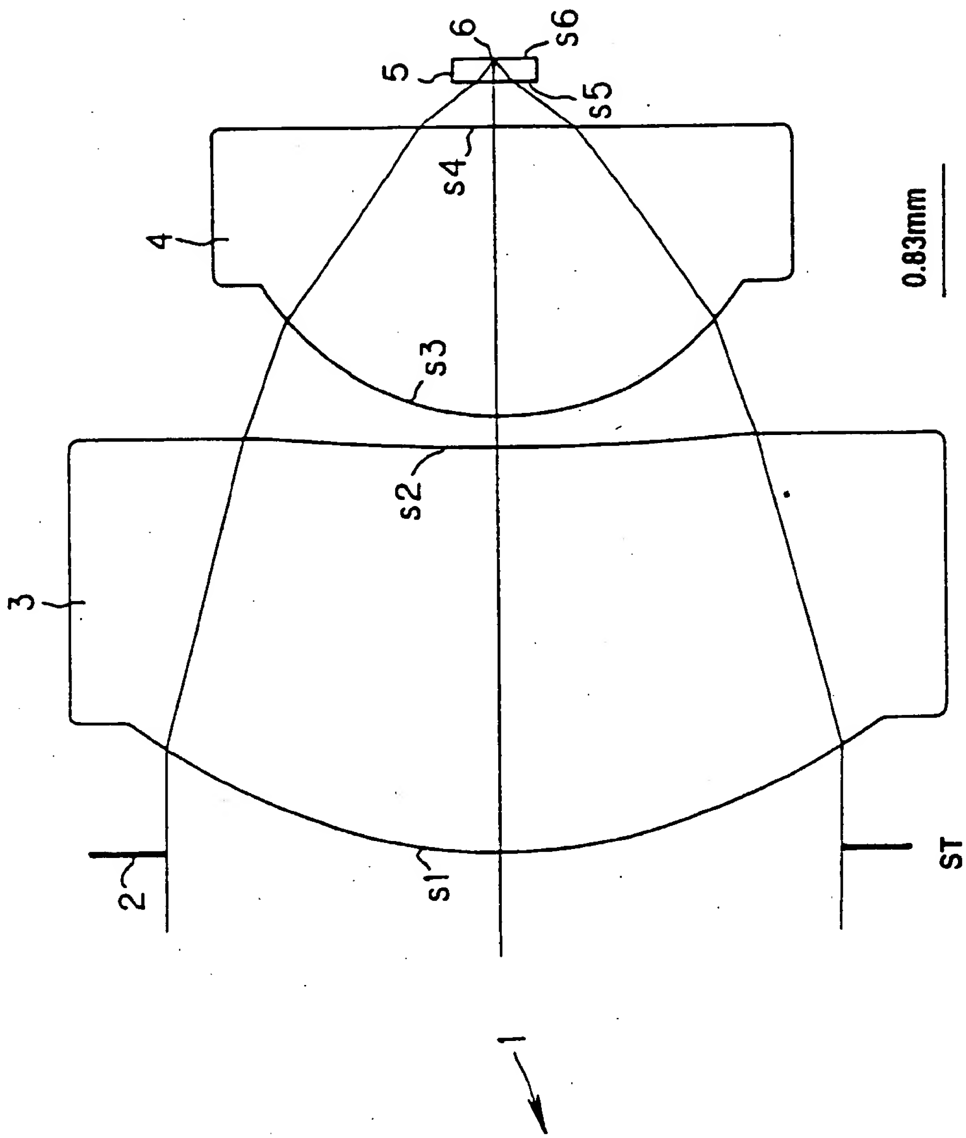
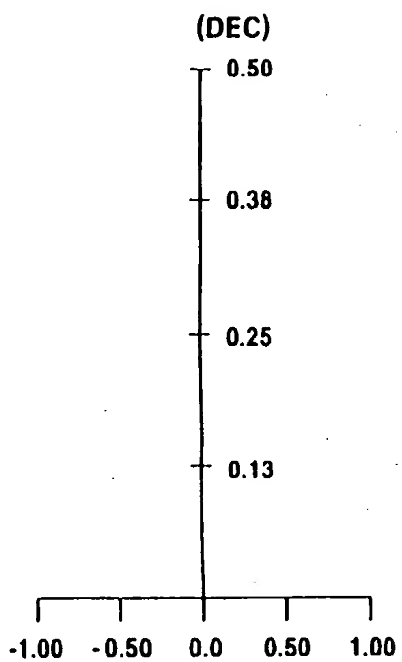
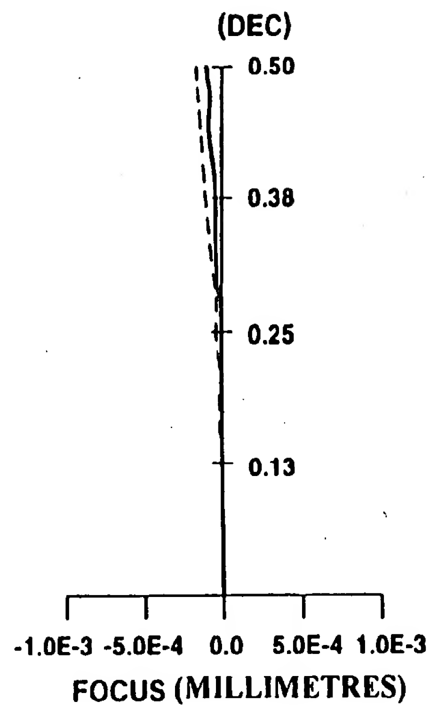


FIG.30



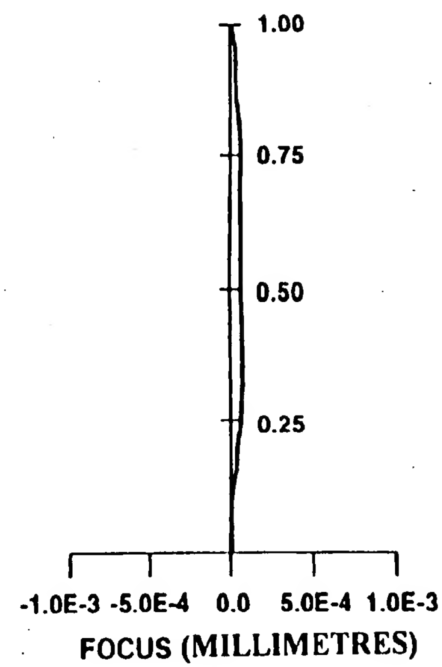
DISTORTION

FIG.31



ASTIGMATIC
FIELD CURVES

FIG.32



LONGITUDINAL
SPHERICAL ABER

FIG.33

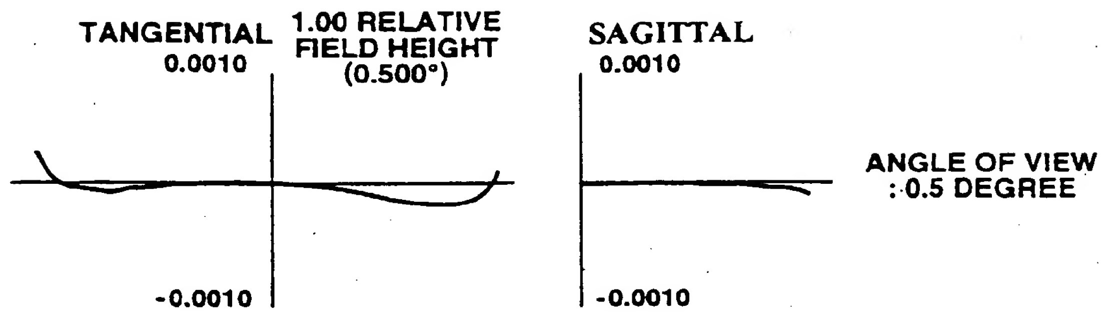

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
ANGLE OF VIEW
: 0.5 DEGREE
-0.0010
-0.0010

FIG.34

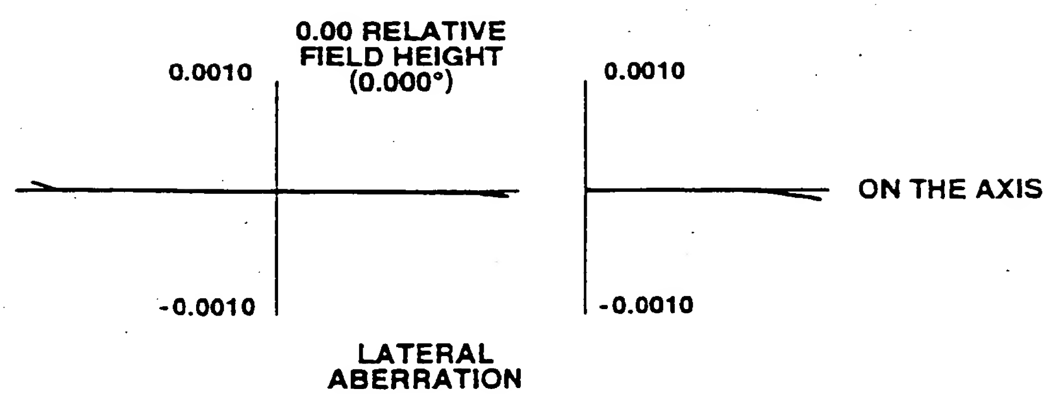

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
ON THE AXIS
-0.0010
-0.0010
LATERAL
ABERRATION

FIG.35

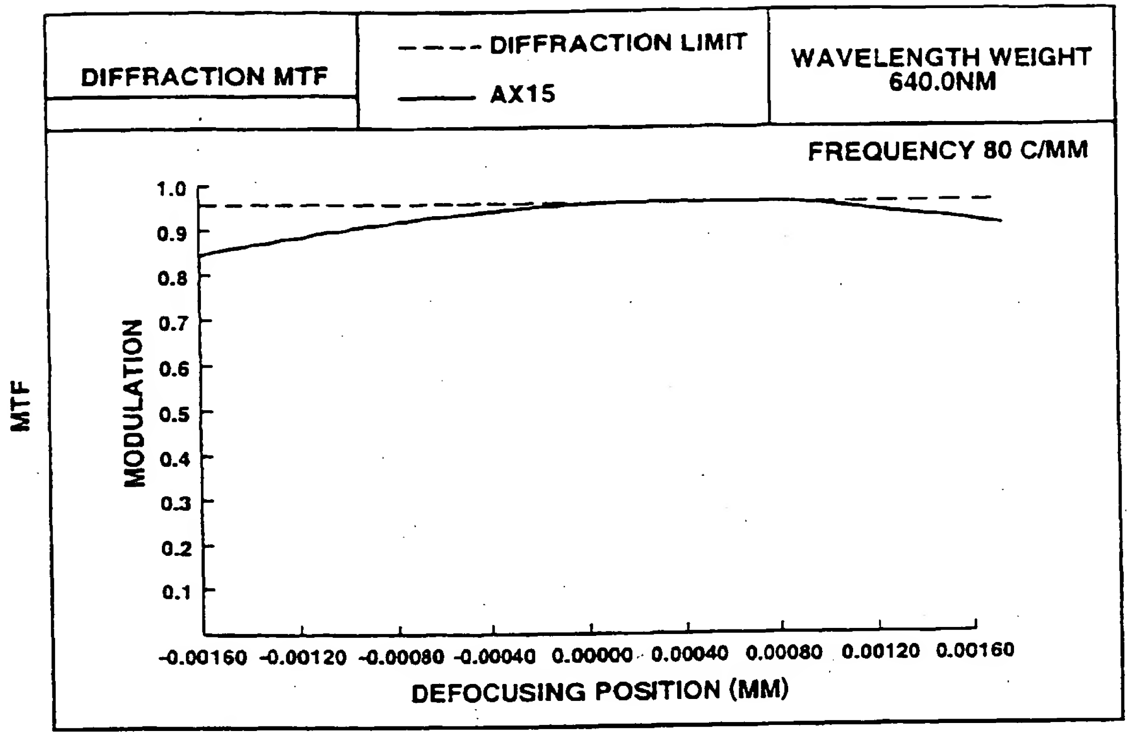

DIFFRACTION MTF
- - - - DIFFRACTION LIMIT
——— AX15
WAVELENGTH WEIGHT
640.0NM
FREQUENCY 80 C/MM
MTF
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.00160 -0.00120 -0.00080 -0.00040 0.00000 0.00040 0.00080 0.00120 0.00160
DEFOCUSING POSITION (MM)

FIG.36

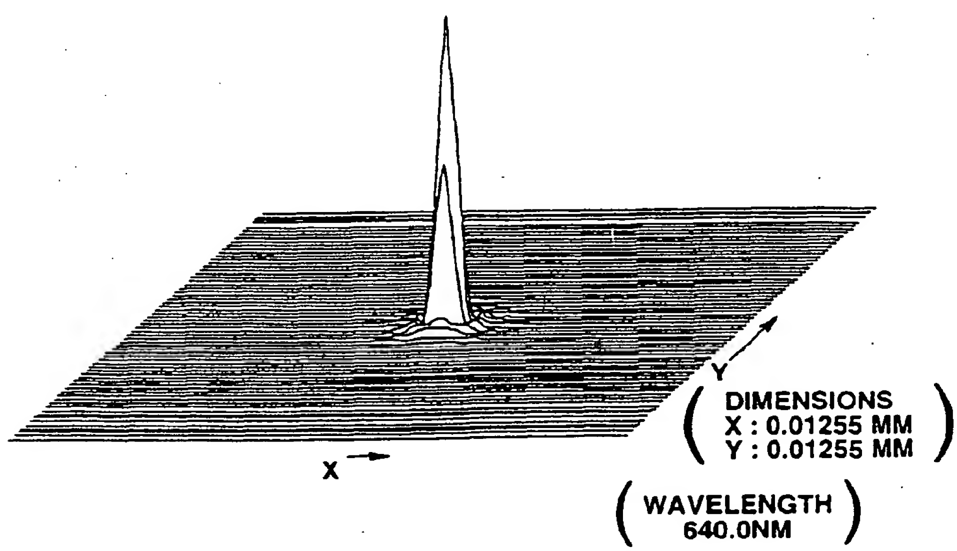

Y
X
DIMENSIONS
X : 0.01255 MM
Y : 0.01255 MM
WAVELENGTH
640.0NM

FIG.37

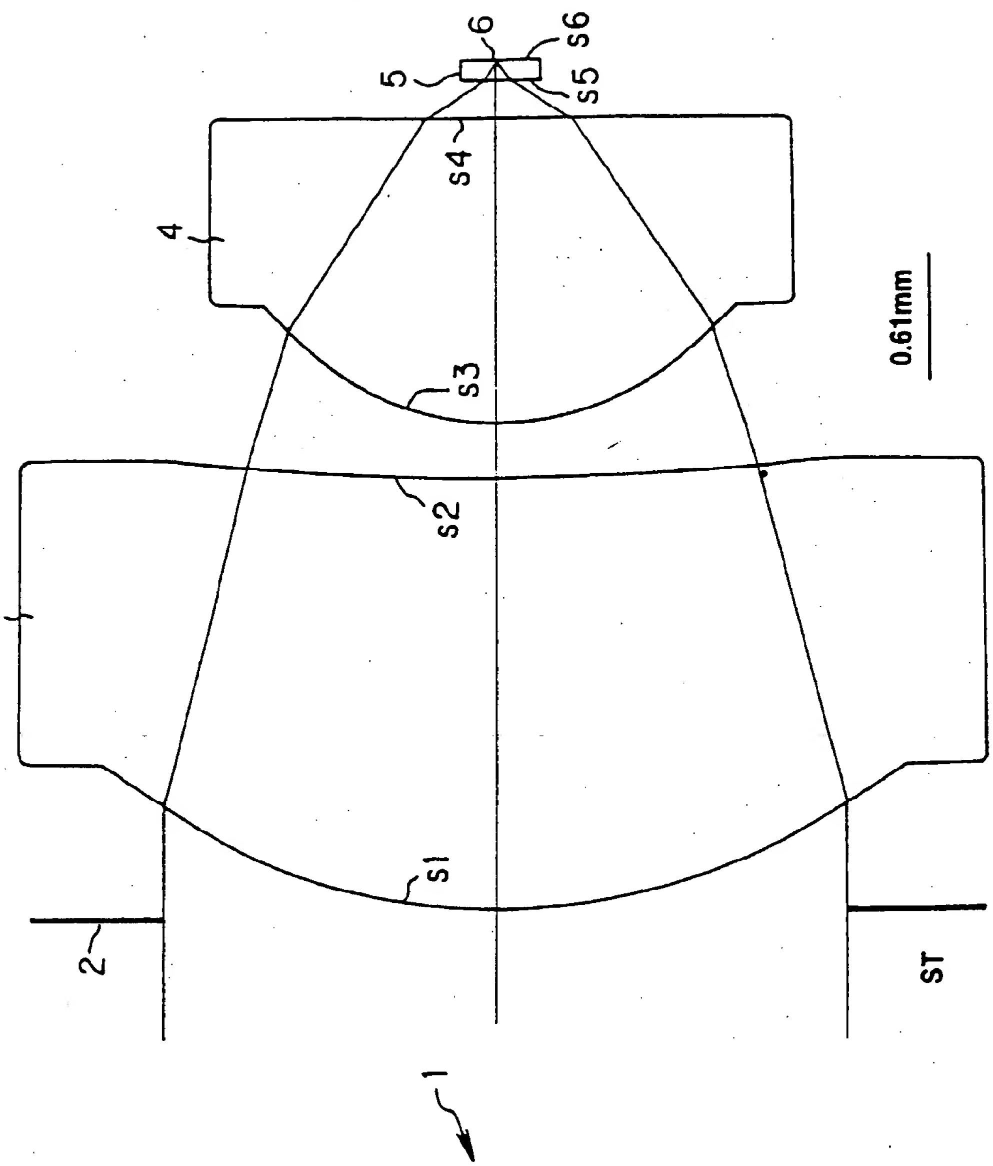
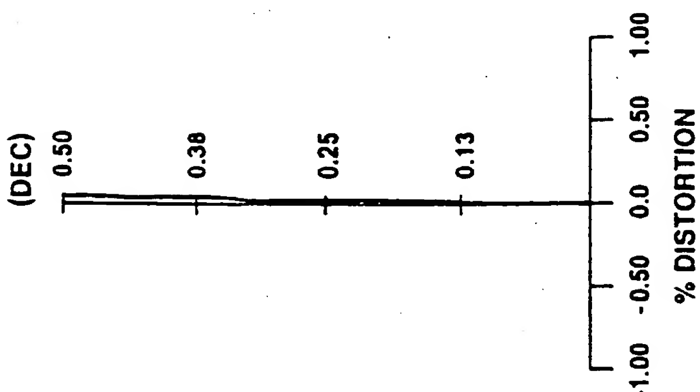
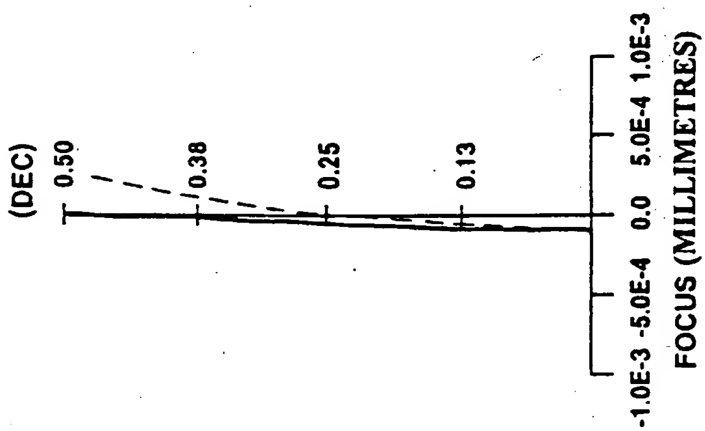


FIG.38



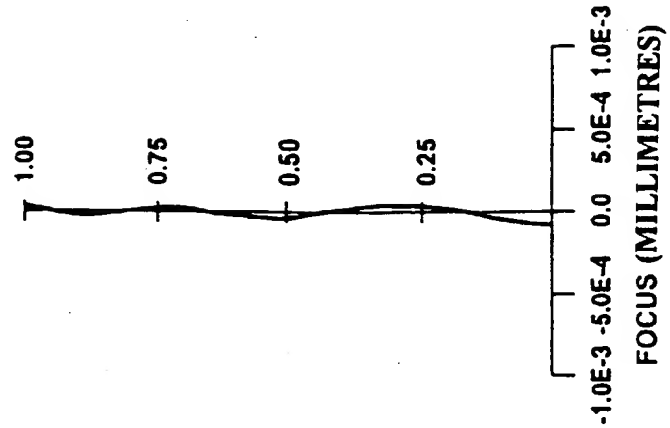
DISTORTION

FIG.39



ASTIGMATIC
FIELD CURVES

FIG.40



LONGITUDINAL
SPHERICAL ABER

FIG.41

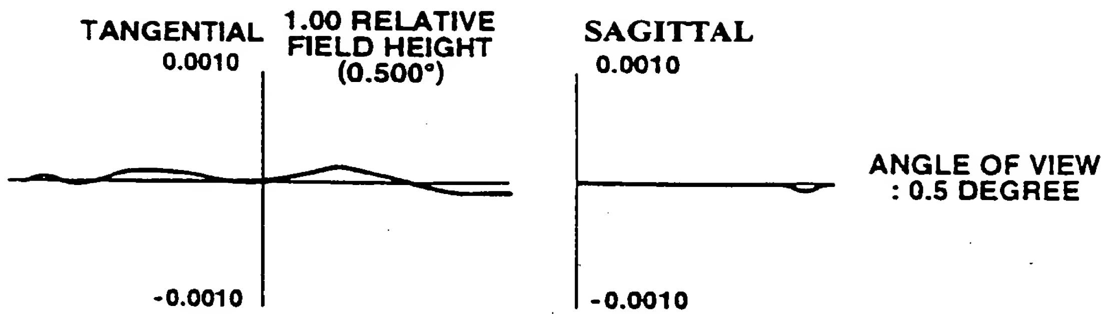

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
ANGLE OF VIEW
: 0.5 DEGREE
-0.0010
-0.0010

FIG.42

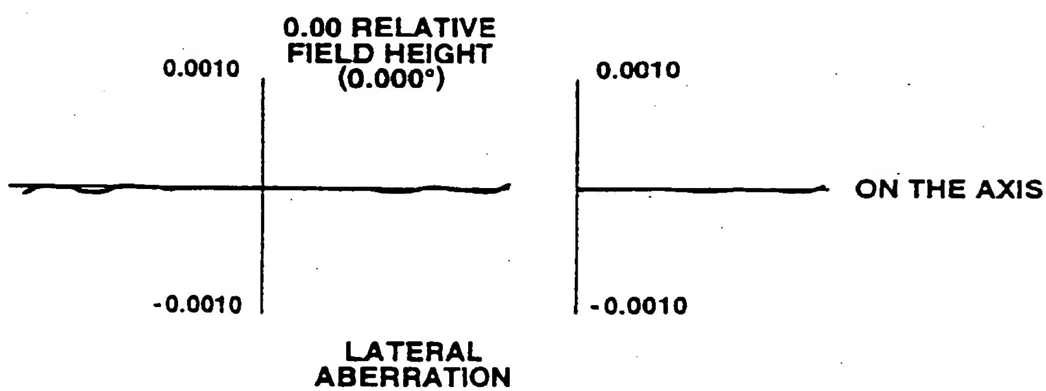

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
ON THE AXIS
-0.0010
-0.0010
LATERAL
ABERRATION

FIG.43

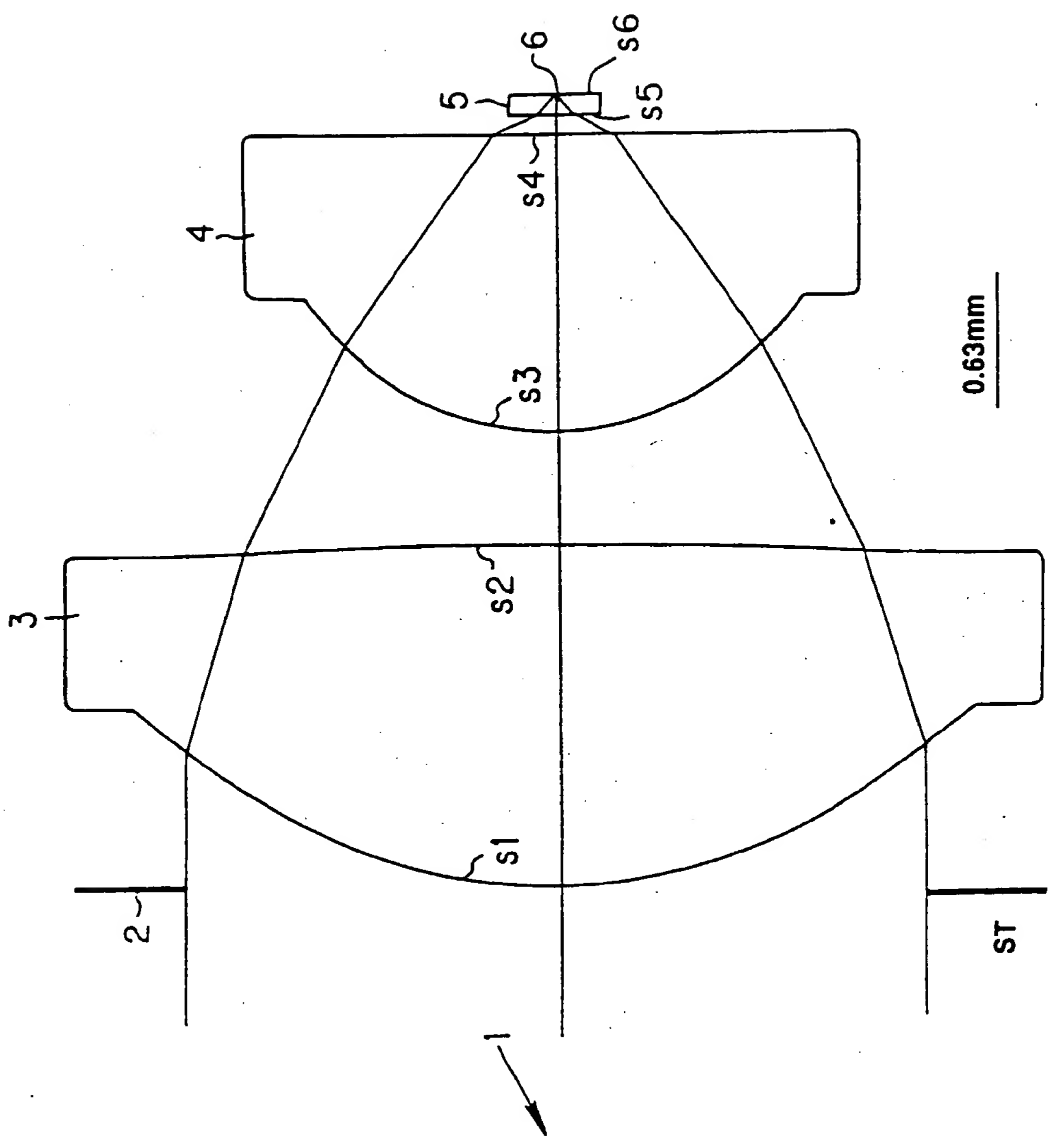
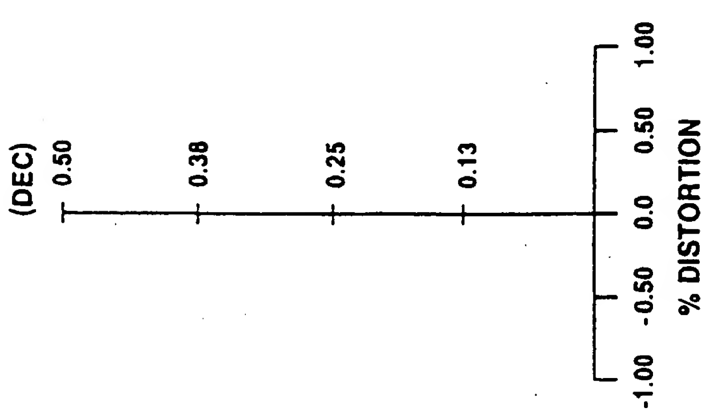
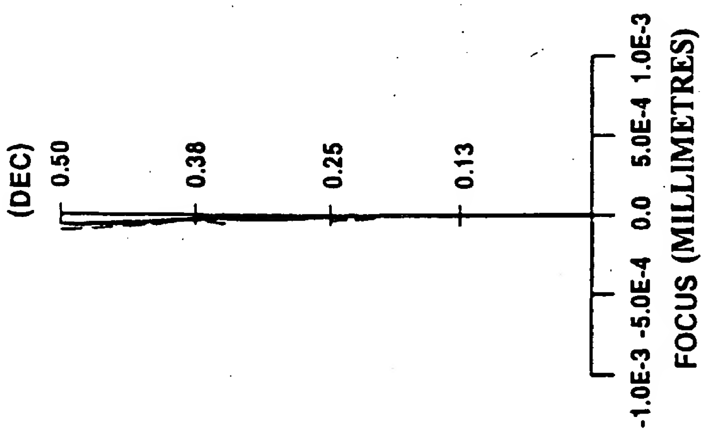


FIG.44



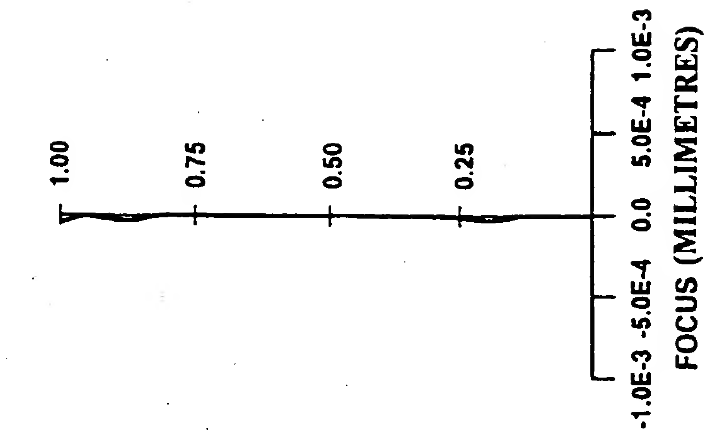
DISTORTION

FIG.45



ASTIGMATIC
FIELD CURVES

FIG.46



LONGITUDINAL
SPHERICAL ABER

FIG.47

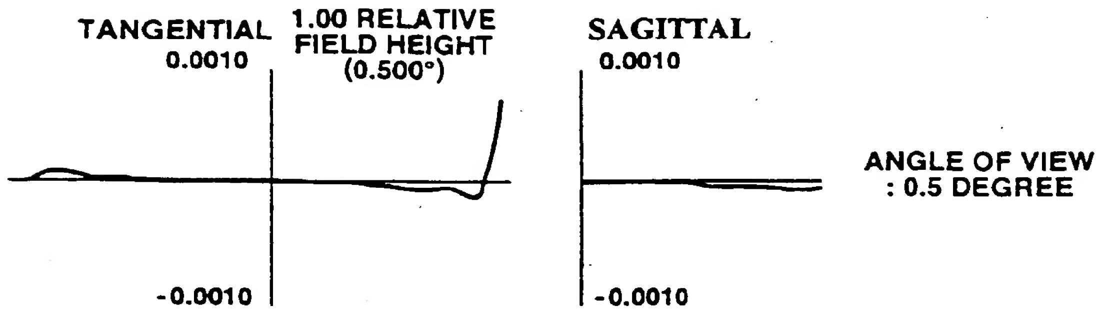

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
-0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.48

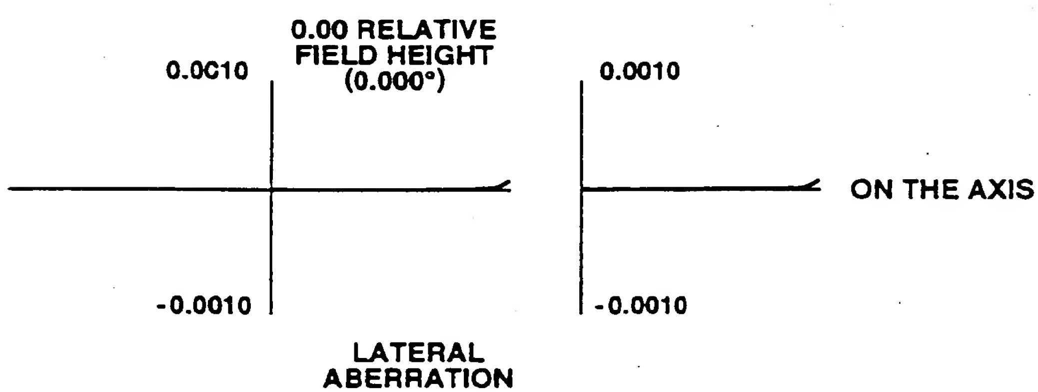

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
-0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.49

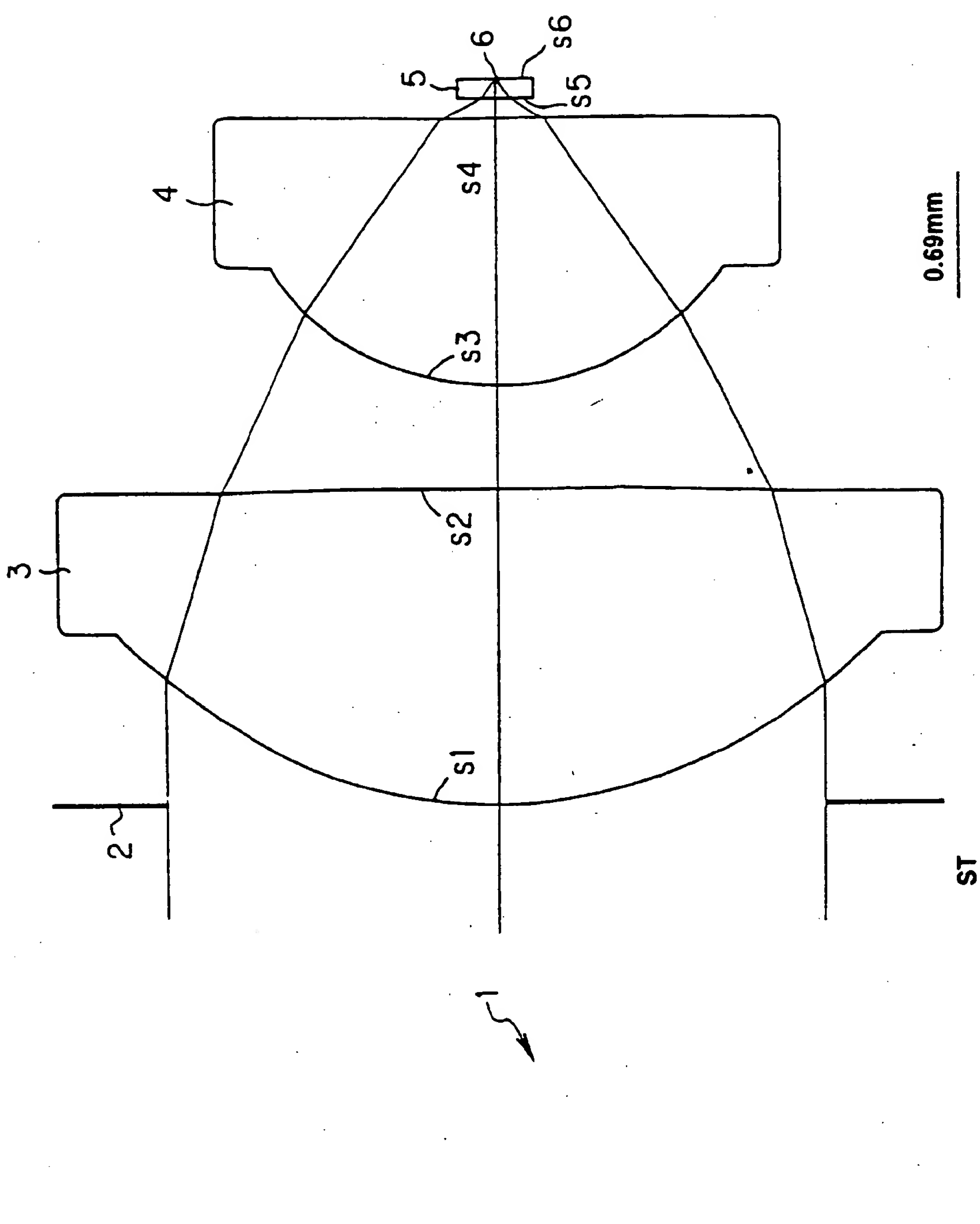
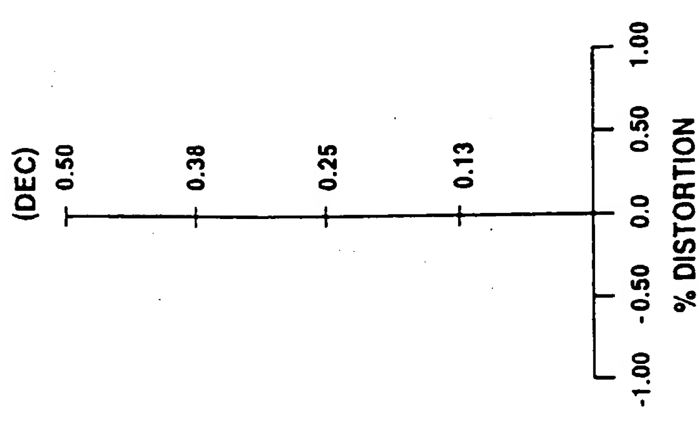
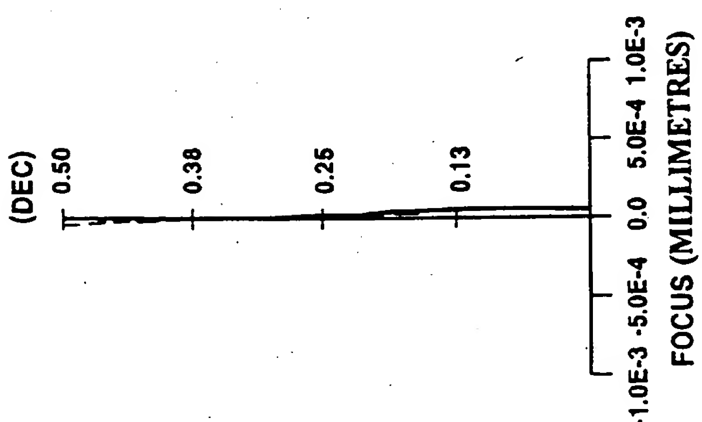


FIG.50



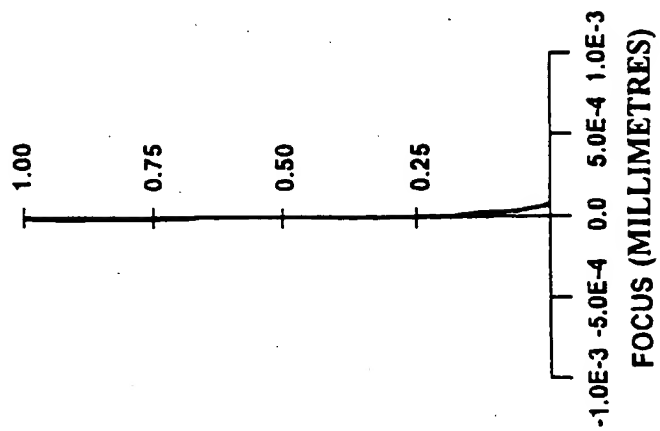
DISTORTION

FIG.51



ASTIGMATIC
FIELD CURVES

FIG.52



LONGITUDINAL
SPHERICAL ABER

FIG.53

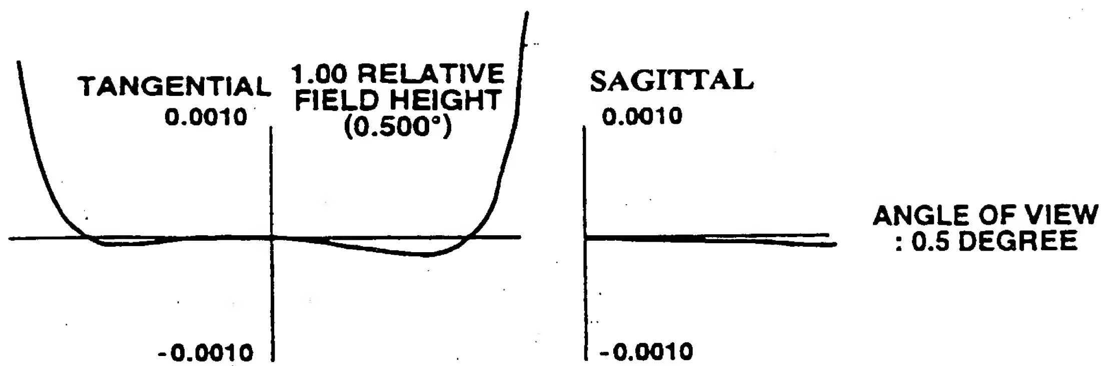

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
0.0010
-0.0010
SAGITTAL
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.54

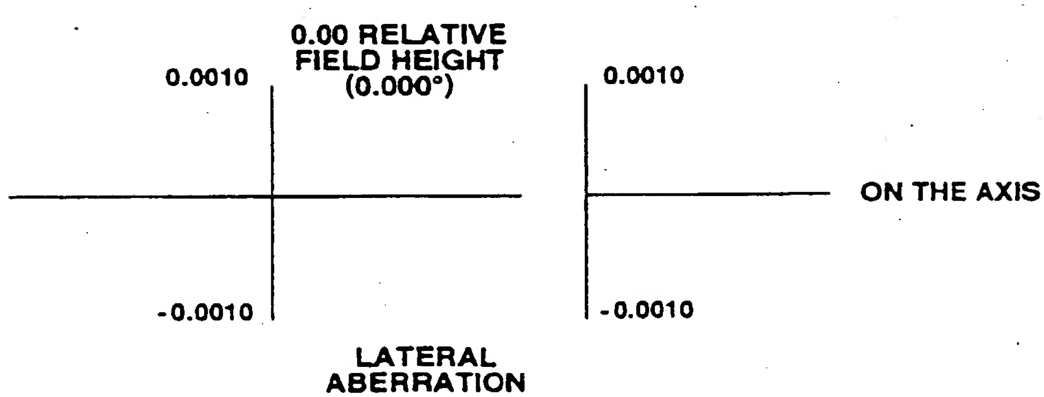

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.55

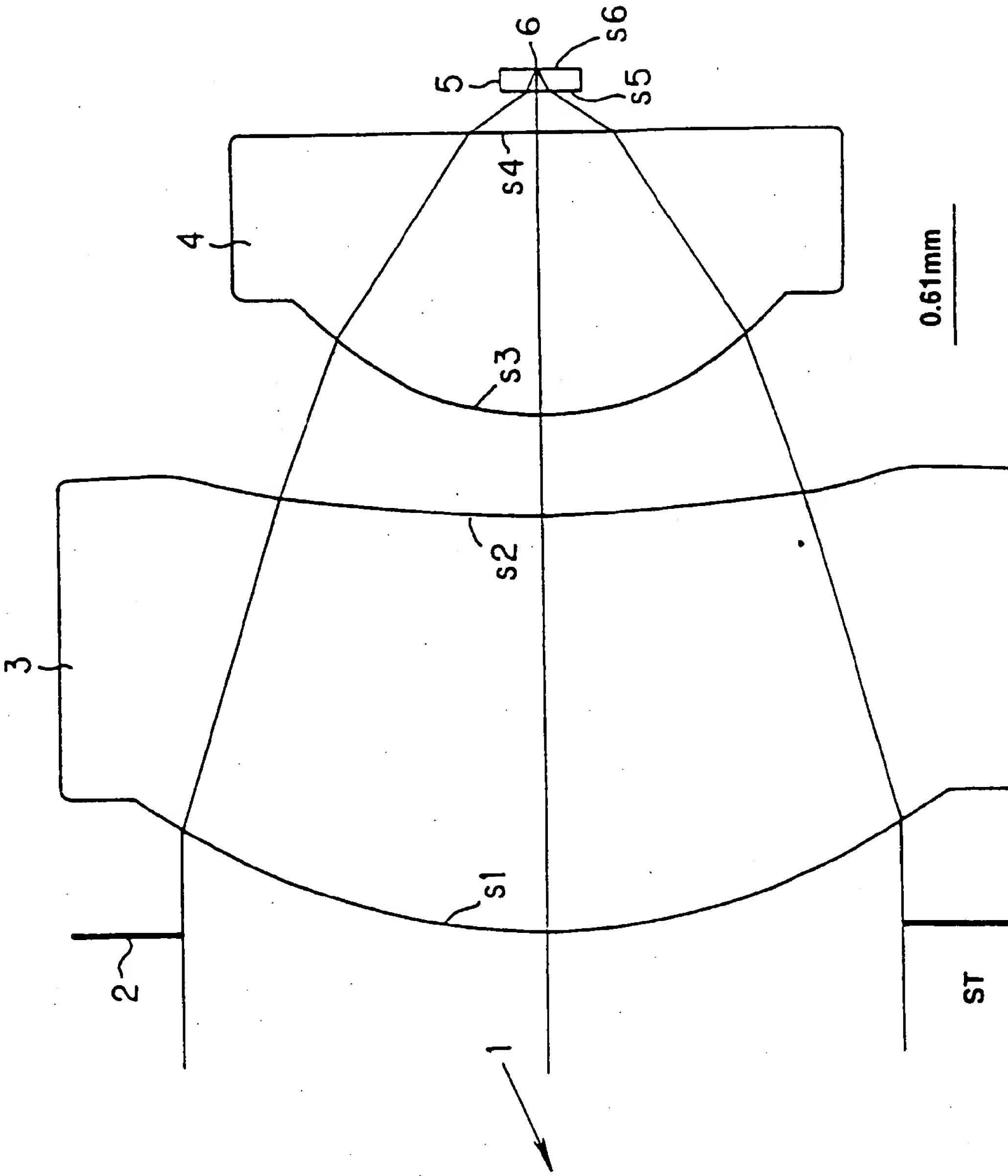
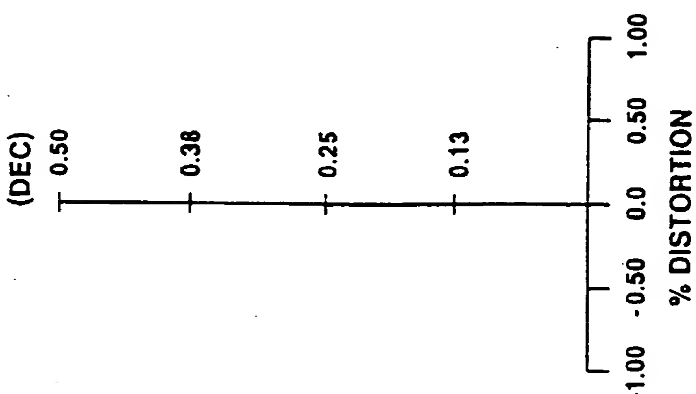
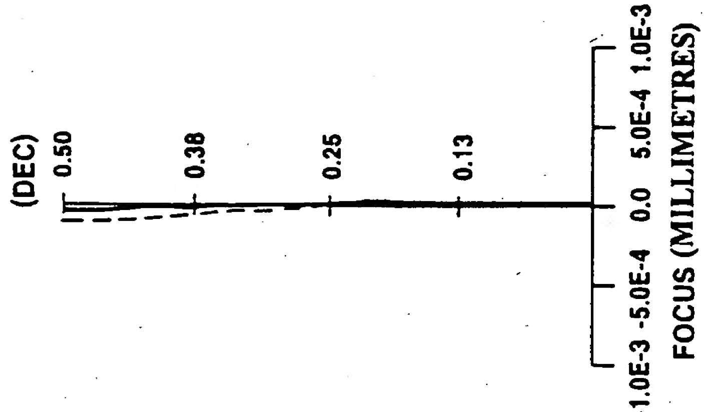


FIG.56



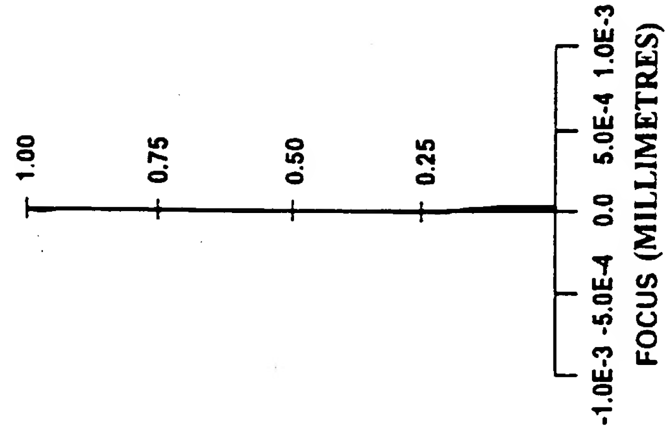
DISTORTION

FIG.57



ASTIGMATIC
FIELD CURVES

FIG.58



LONGITUDINAL
SPHERICAL ABER

FIG.59

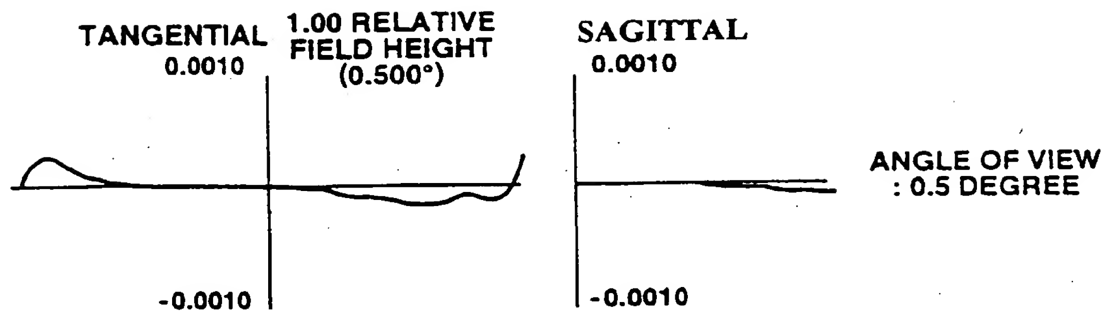

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
ANGLE OF VIEW
: 0.5 DEGREE
-0.0010
-0.0010

FIG.60

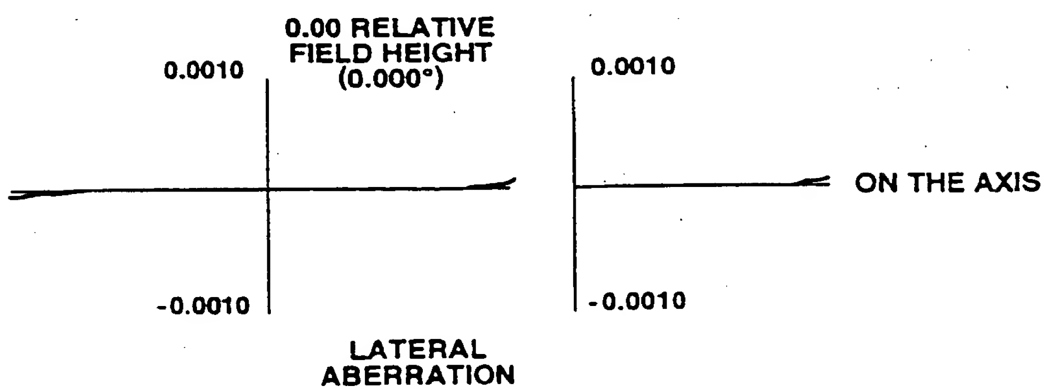

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
ON THE AXIS
-0.0010
-0.0010
LATERAL
ABERRATION

FIG.61

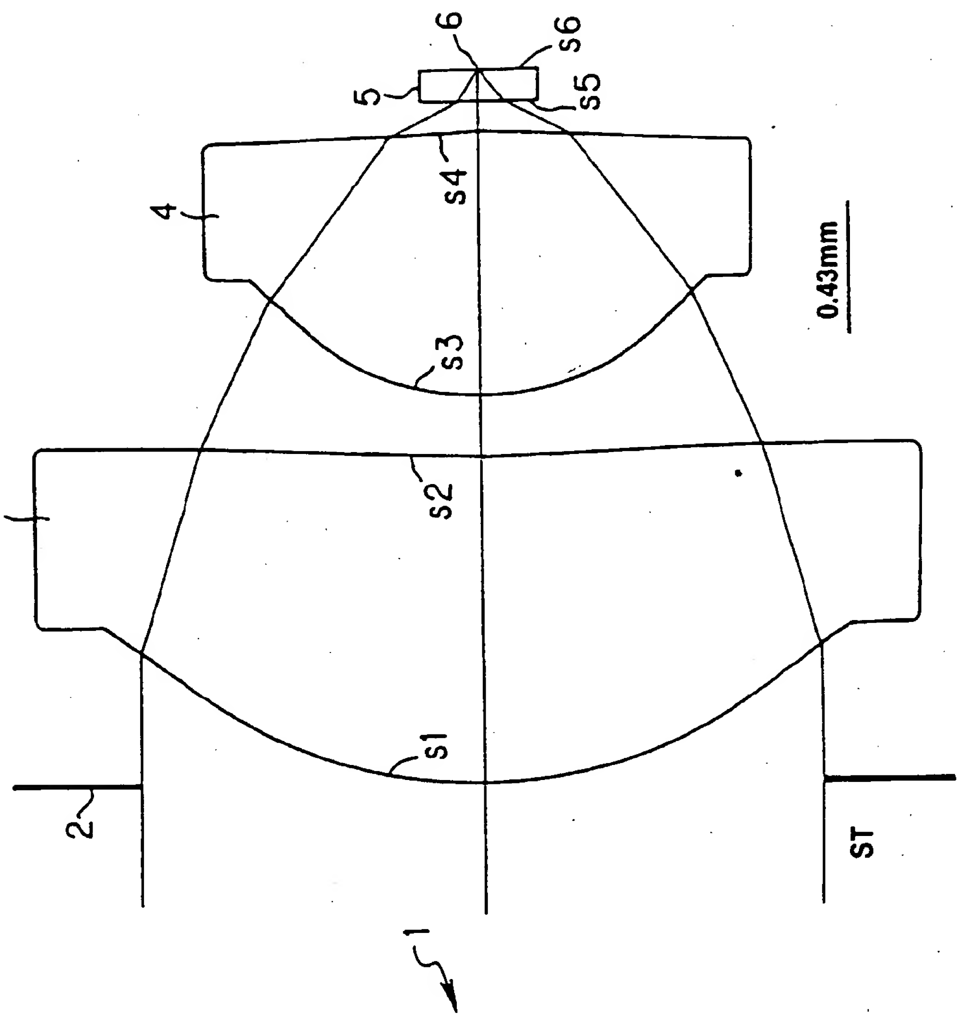


FIG.62

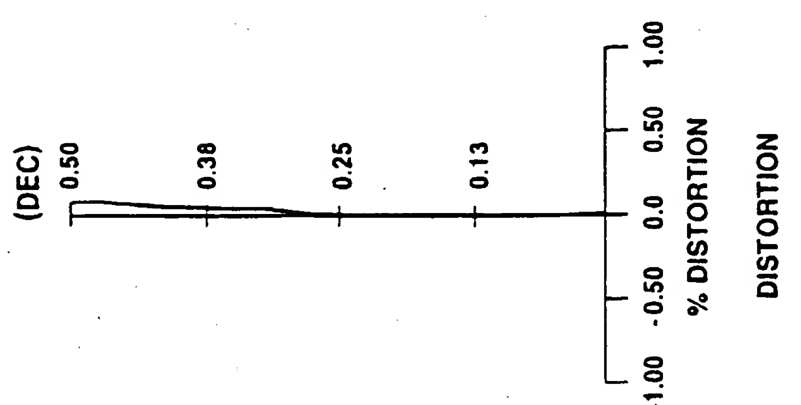


FIG.63

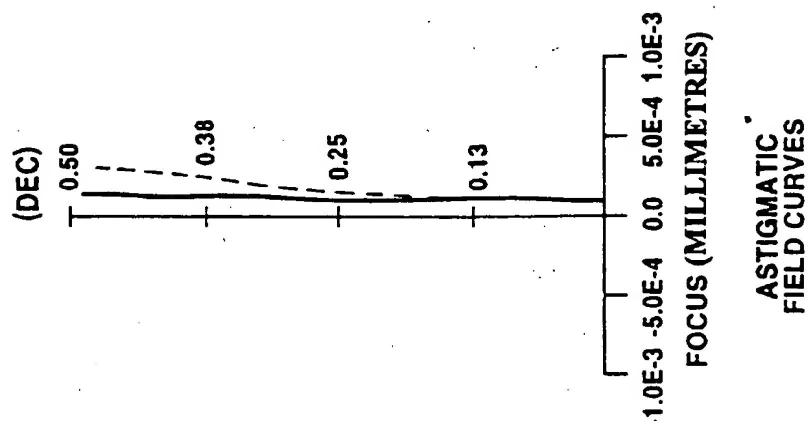


FIG.64

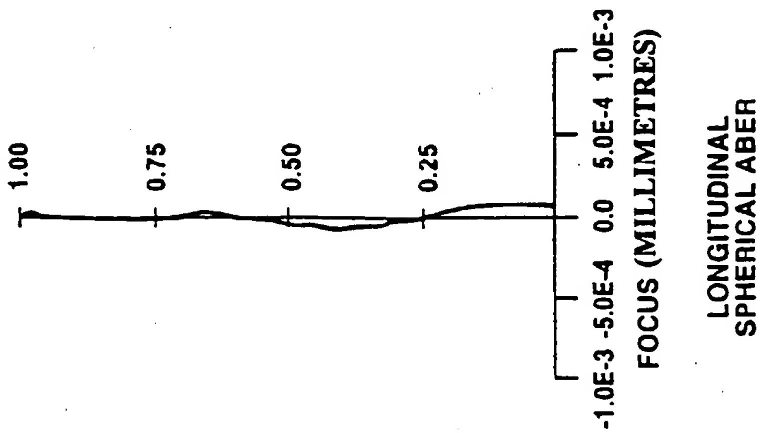


FIG.65

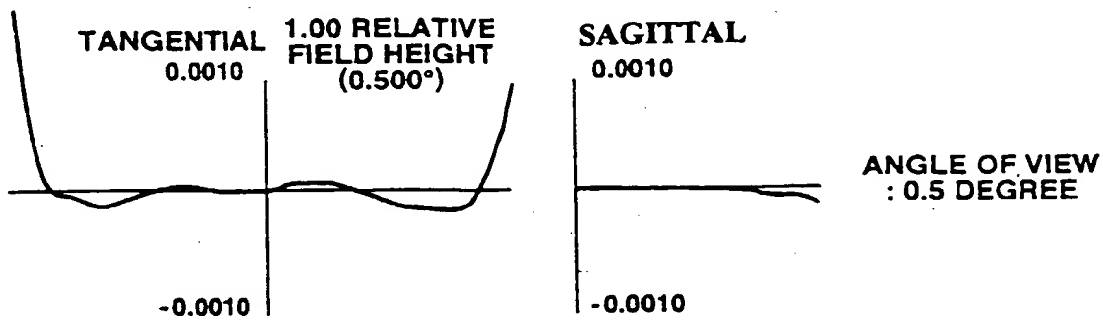

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
0.0010
-0.0010
SAGITTAL
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.66

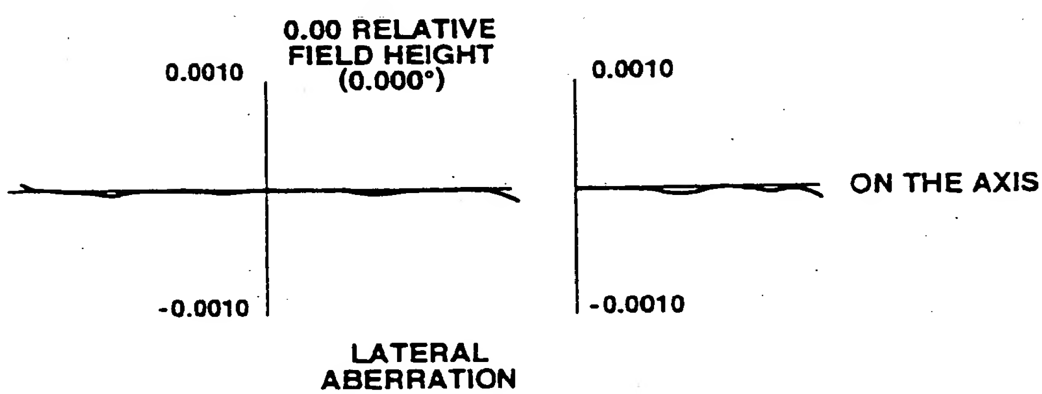

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.67

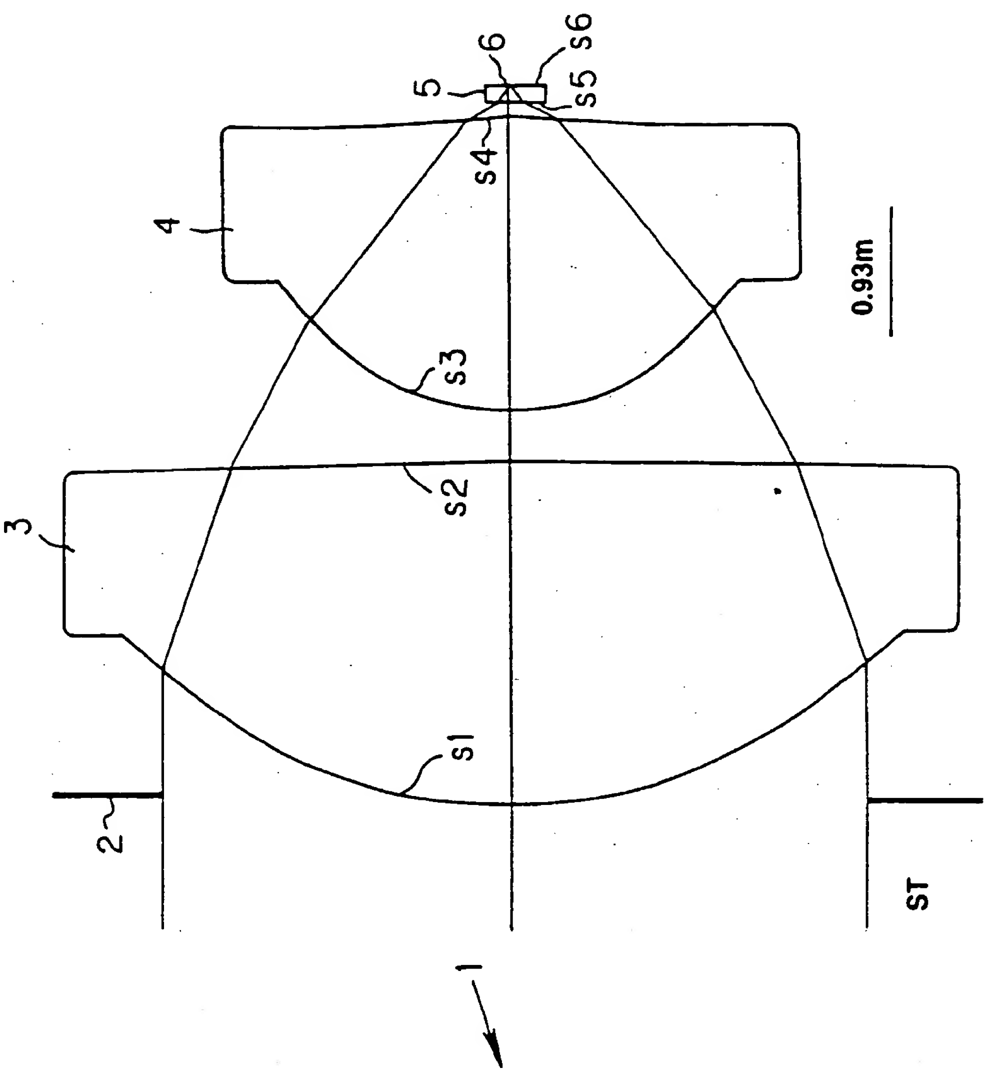
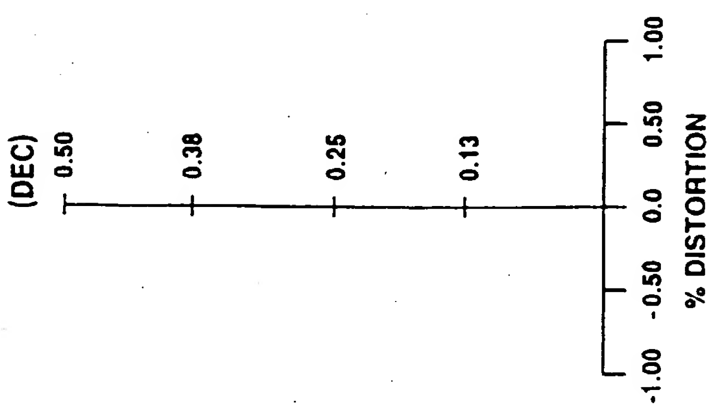
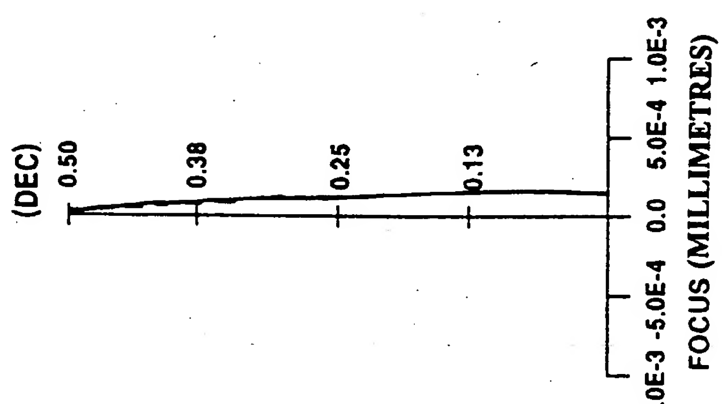


FIG.68



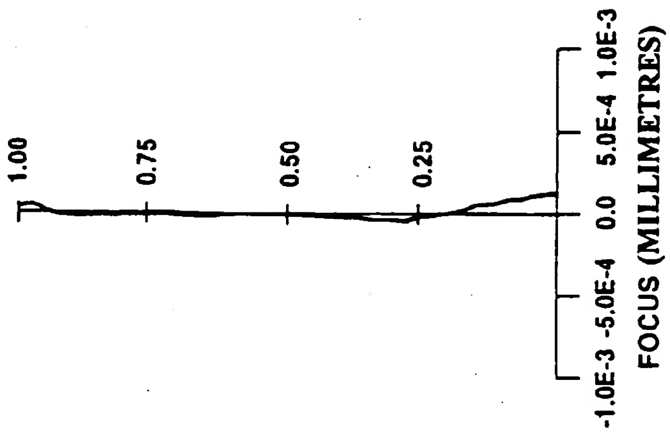
DISTORTION

FIG.69



ASTIGMATIC FIELD CURVES

FIG.70



LONGITUDINAL SPHERICAL ABER

FIG.71

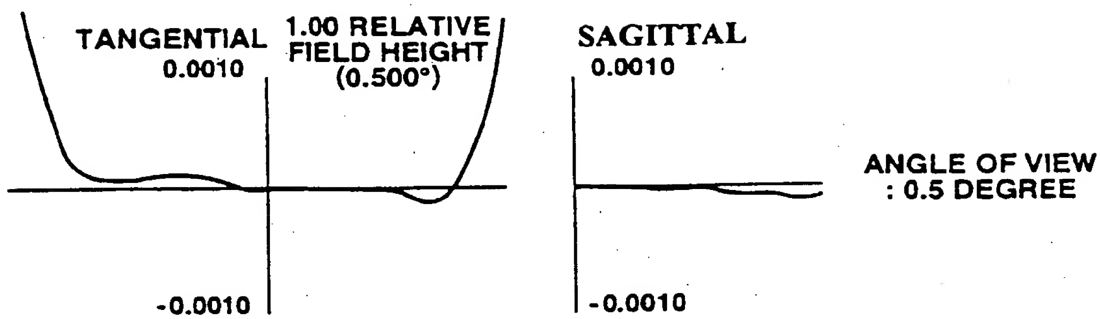

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
0.0010
-0.0010
SAGITTAL
0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.72

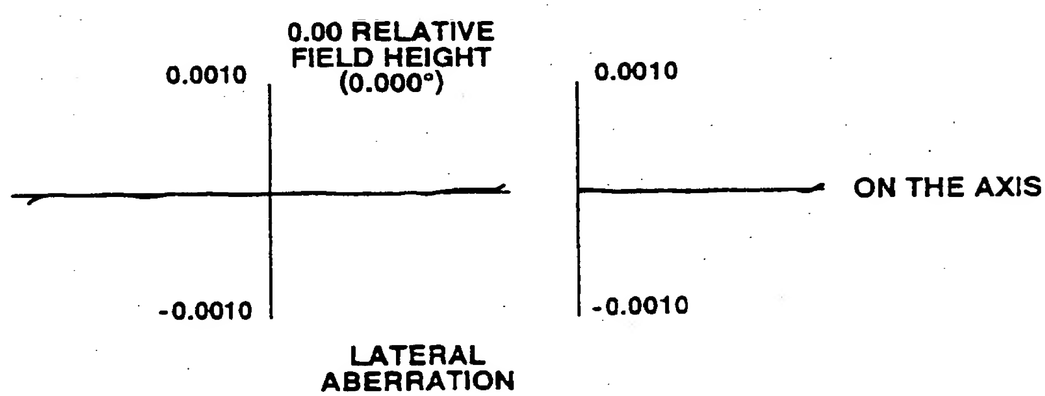

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.73

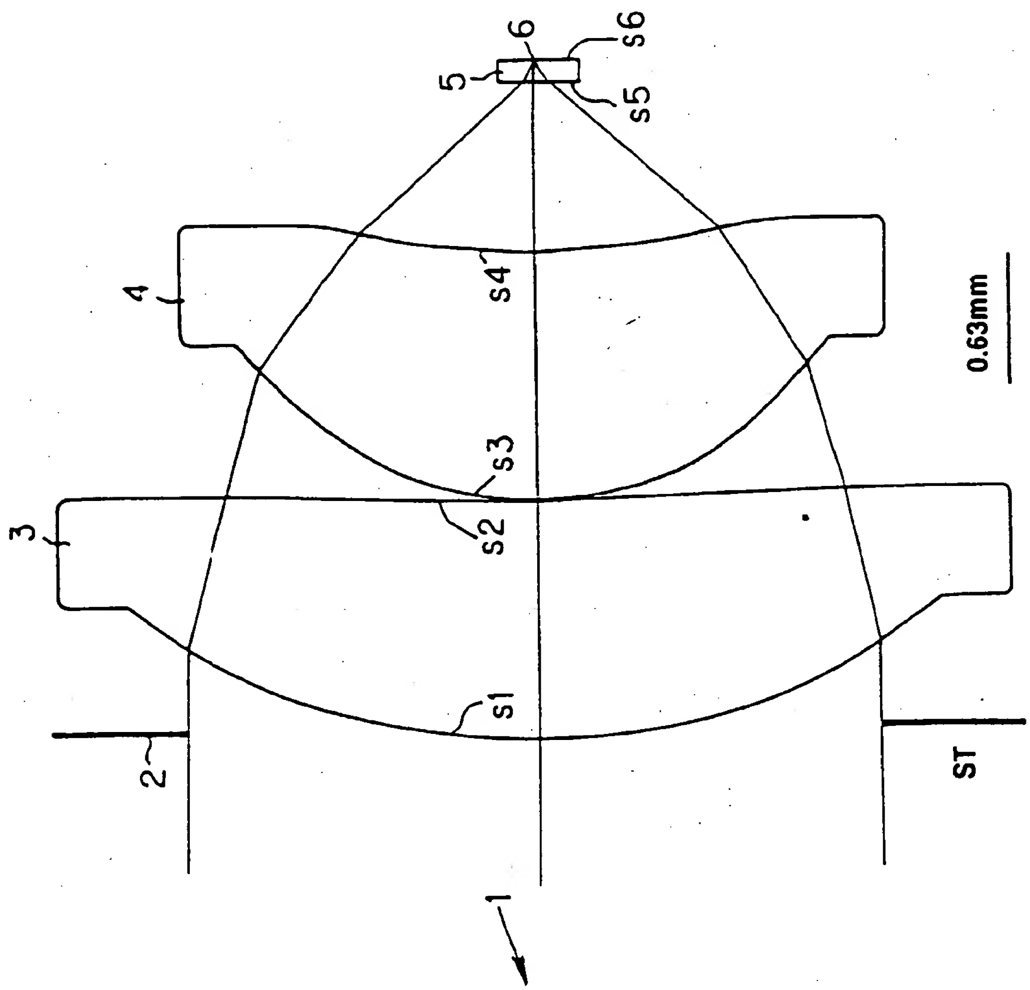


FIG.74

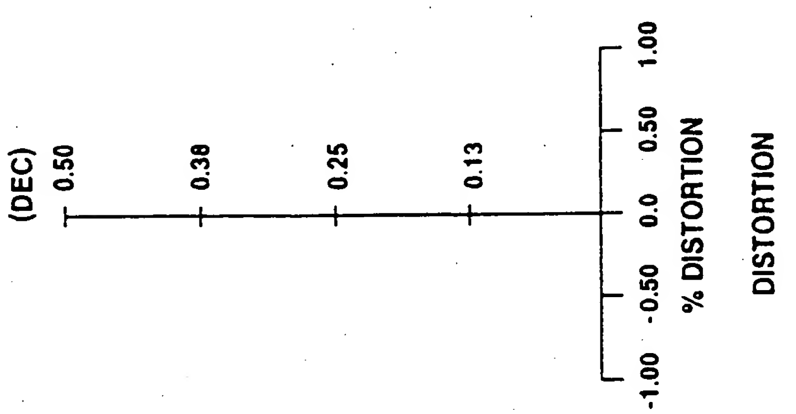


FIG.75

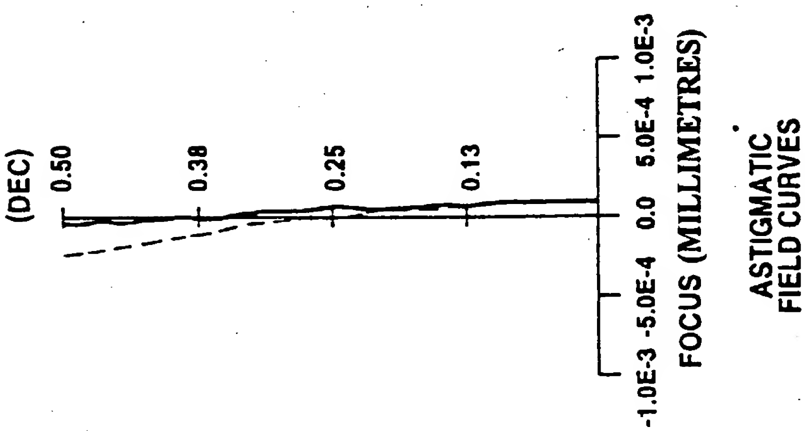


FIG.76

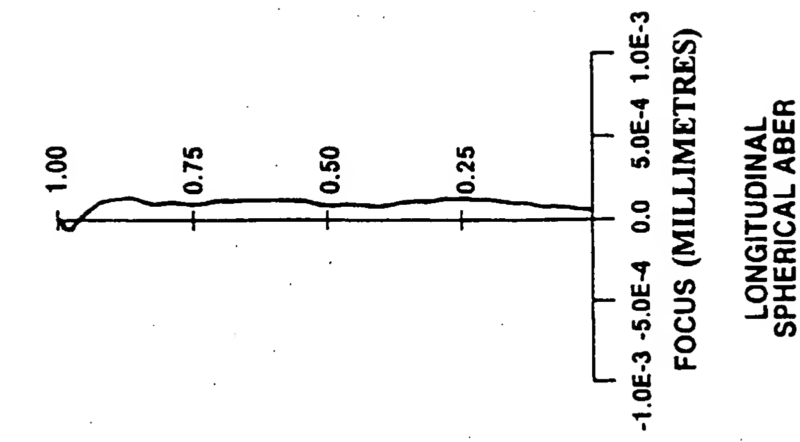


FIG.77

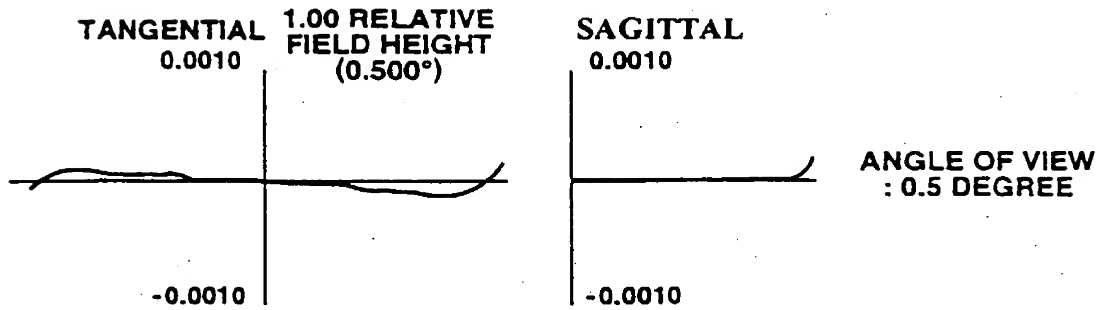

TANGENTIAL
1.00 RELATIVE FIELD HEIGHT (0.500°)
SAGITTAL
0.0010
-0.0010
0.0010
-0.0010
ANGLE OF VIEW : 0.5 DEGREE

FIG.78

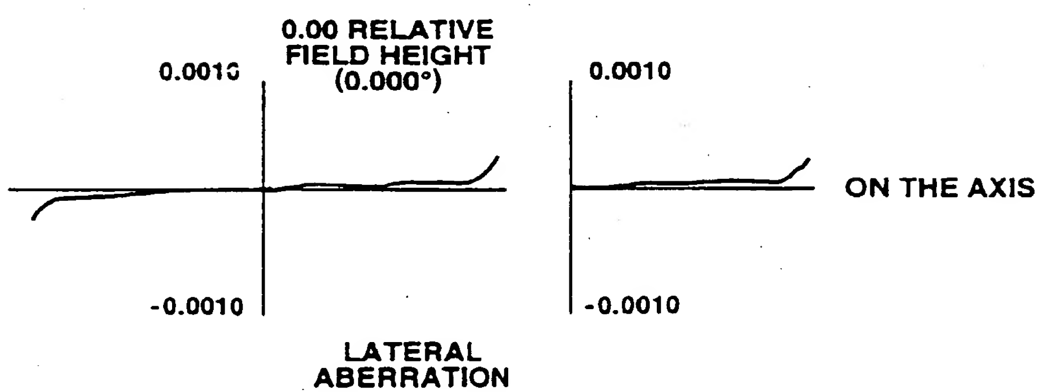

0.00 RELATIVE FIELD HEIGHT (0.000°)
0.0010
-0.0010
0.0010
-0.0010
ON THE AXIS
LATERAL ABERRATION

FIG.79

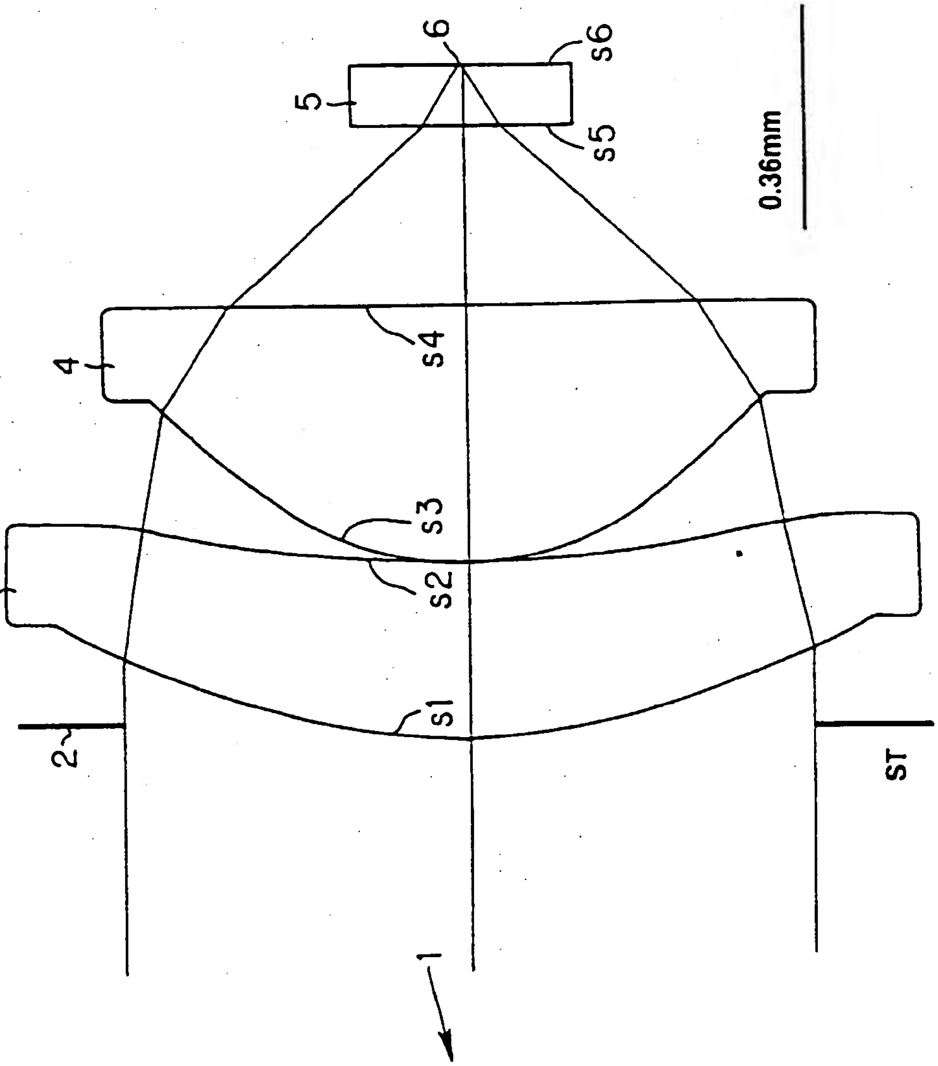
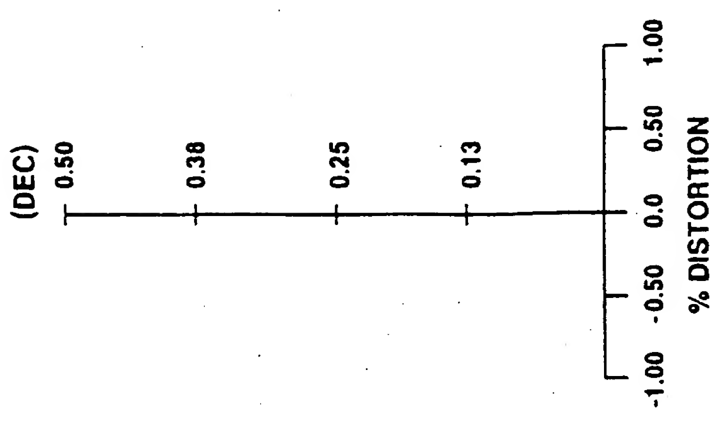
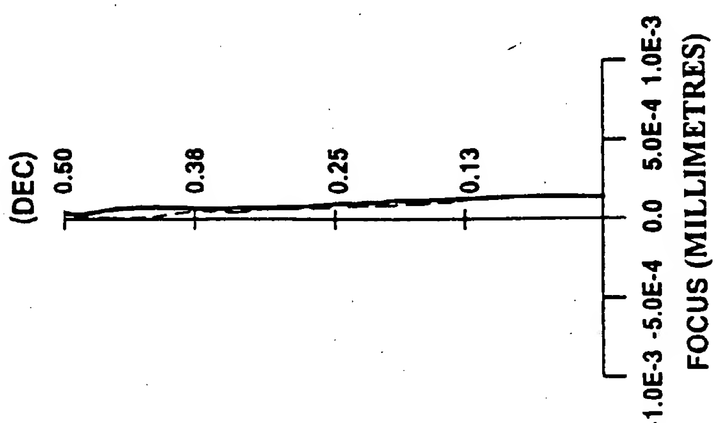


FIG.80



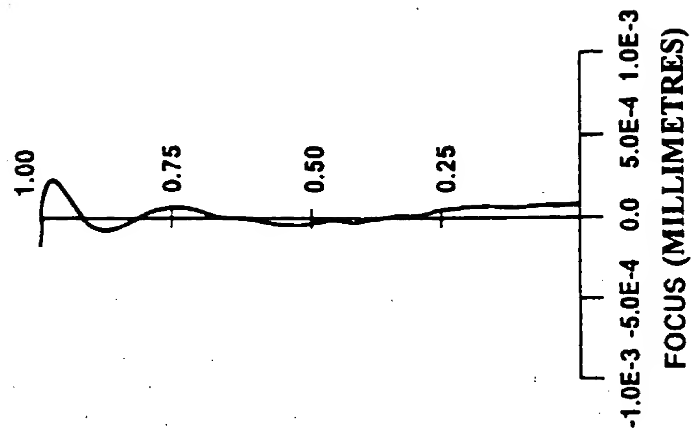
DISTORTION

FIG.81



ASTIGMATIC
FIELD CURVES

FIG.82



LONGITUDINAL
SPHERICAL ABER

FIG.83

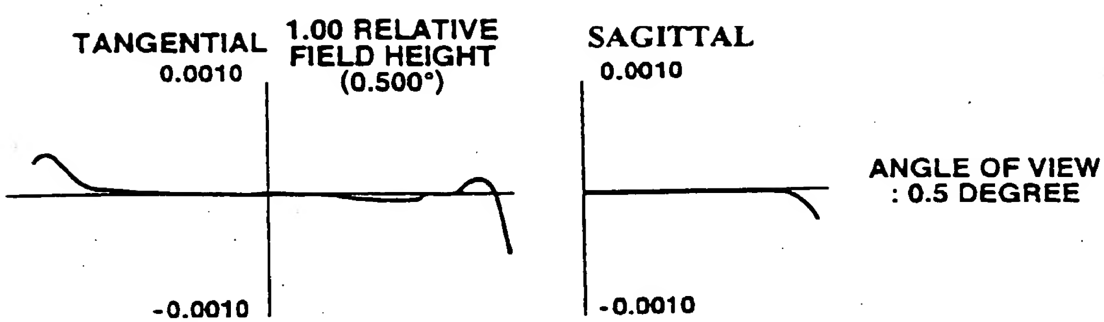

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
-0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.84

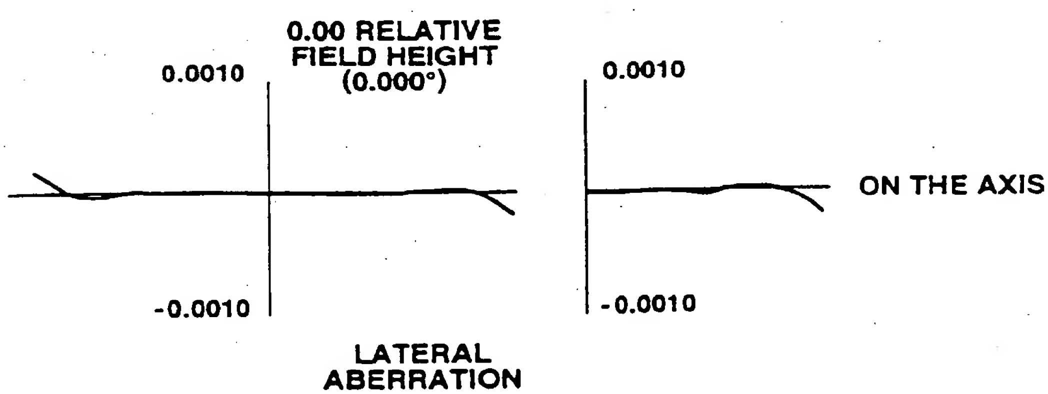

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
-0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.85

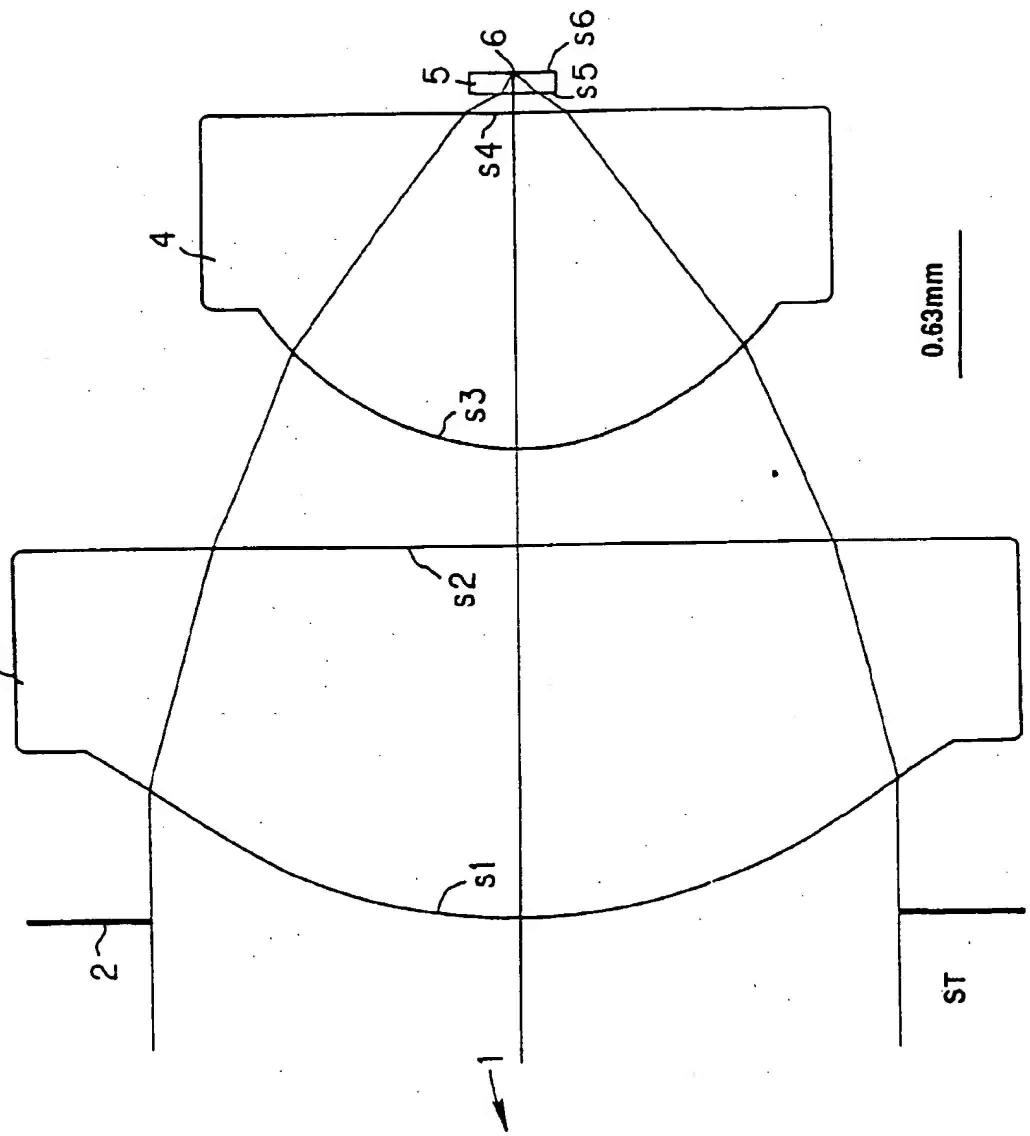


FIG.86

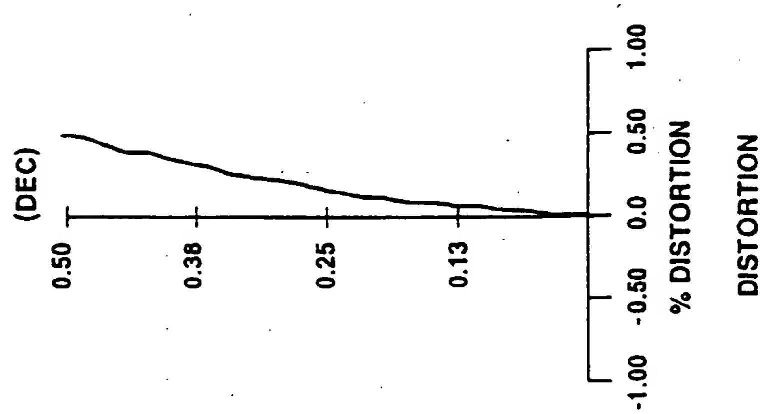


FIG.87

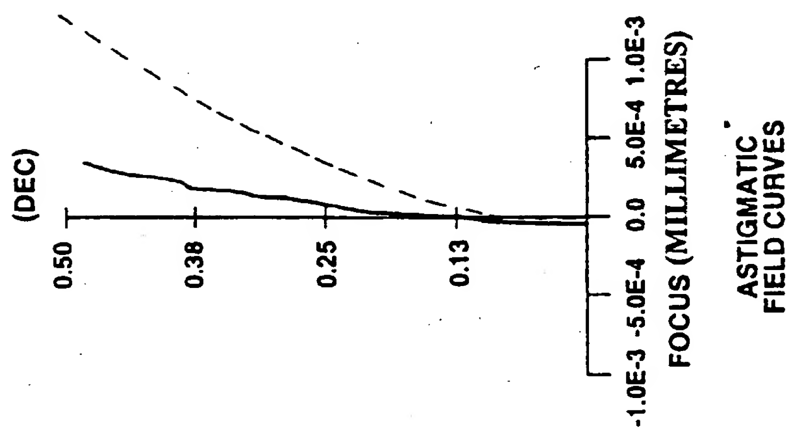


FIG.88

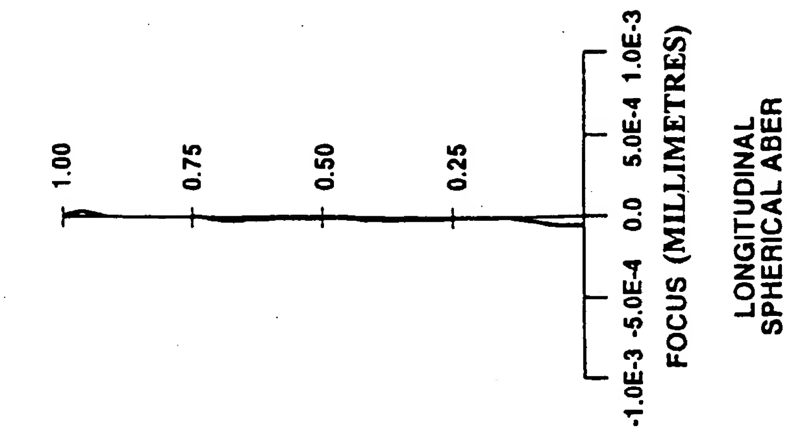


FIG.89

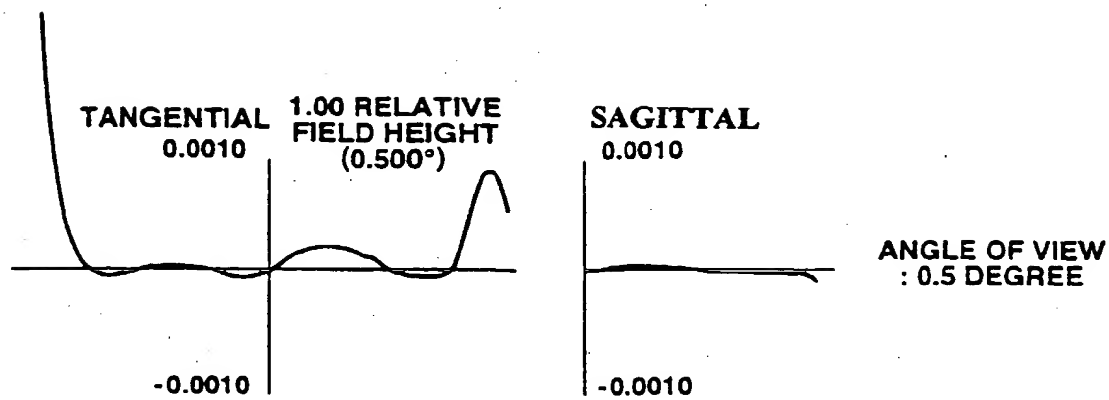

TANGENTIAL
0.0010
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
ANGLE OF VIEW
: 0.5 DEGREE
-0.0010
-0.0010

FIG.90

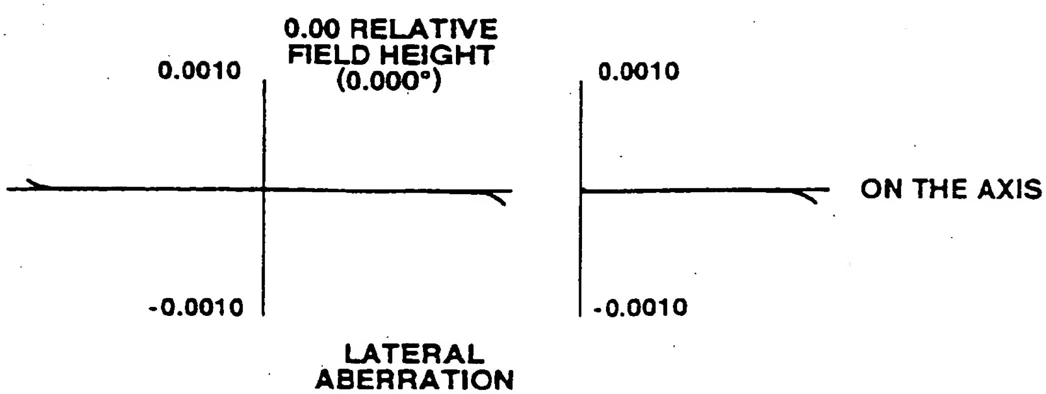

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
ON THE AXIS
-0.0010
-0.0010
LATERAL
ABERRATION

FIG.91

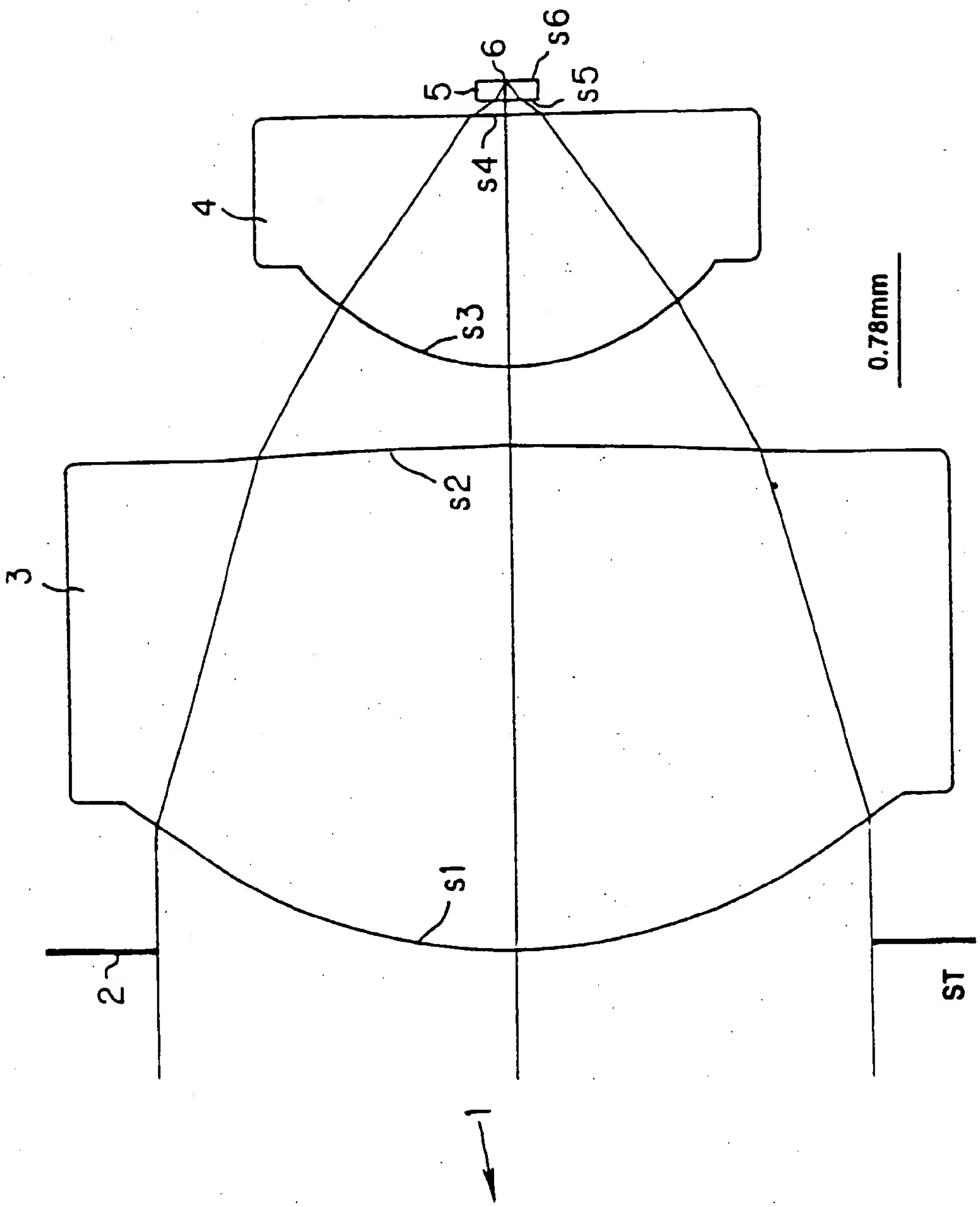
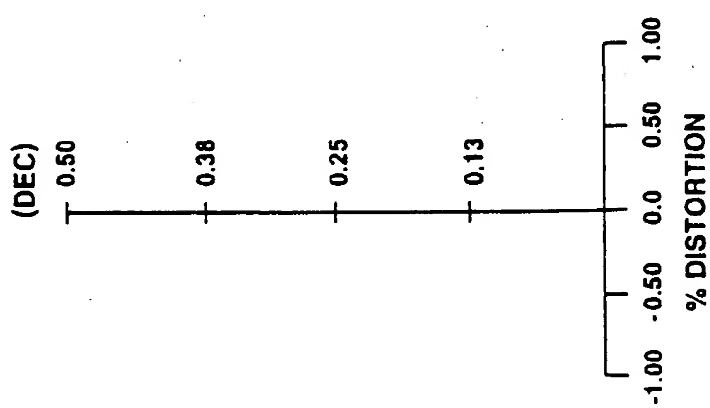
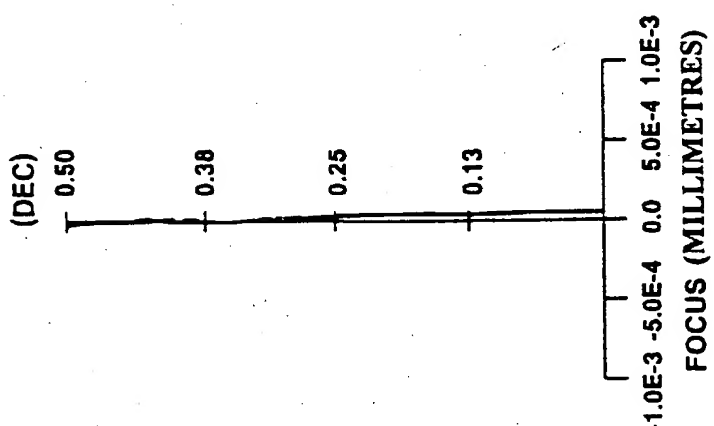


FIG.92



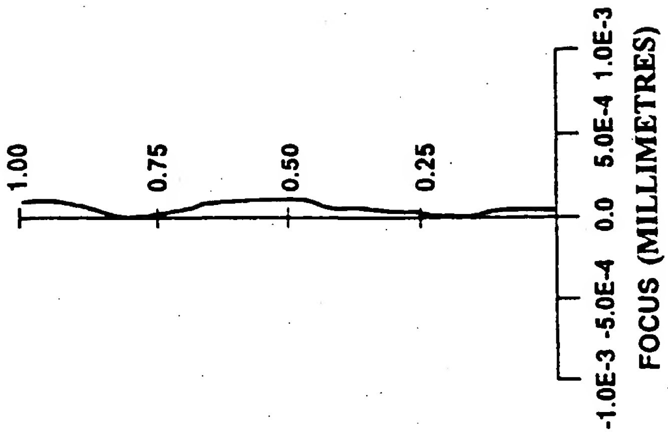
DISTORTION

FIG.93



ASTIGMATIC FIELD CURVES

FIG.94



LONGITUDINAL SPHERICAL ABER

FIG.95

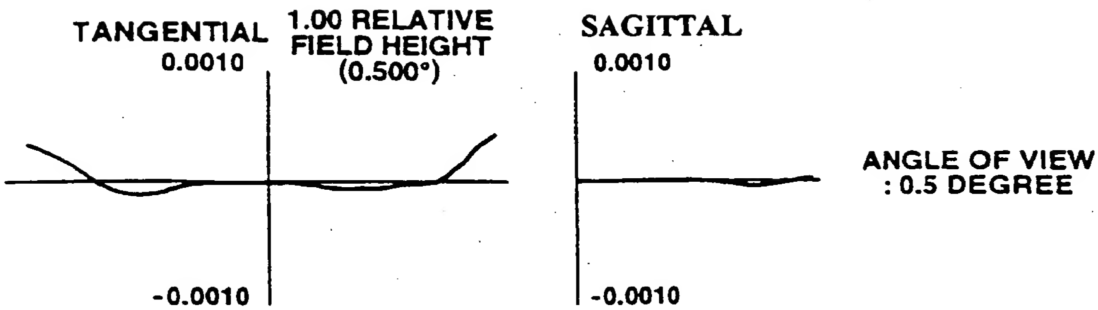

TANGENTIAL
1.00 RELATIVE
FIELD HEIGHT
(0.500°)
SAGITTAL
0.0010
0.0010
-0.0010
-0.0010
ANGLE OF VIEW
: 0.5 DEGREE

FIG.96

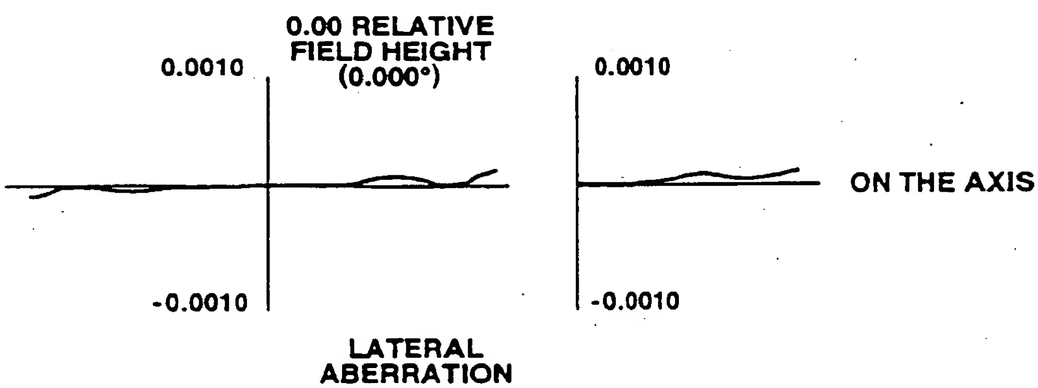

0.00 RELATIVE
FIELD HEIGHT
(0.000°)
0.0010
0.0010
-0.0010
-0.0010
ON THE AXIS
LATERAL
ABERRATION

FIG.97

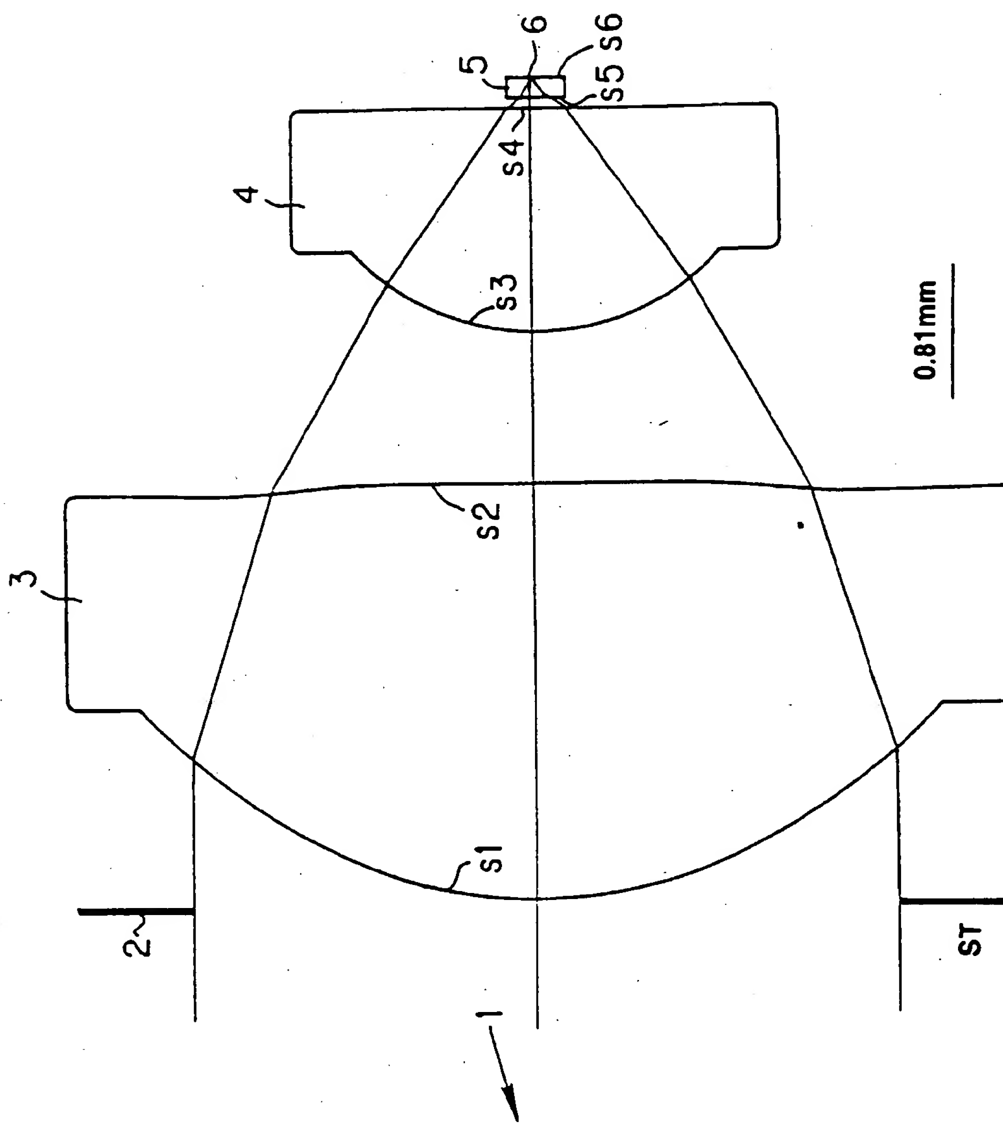
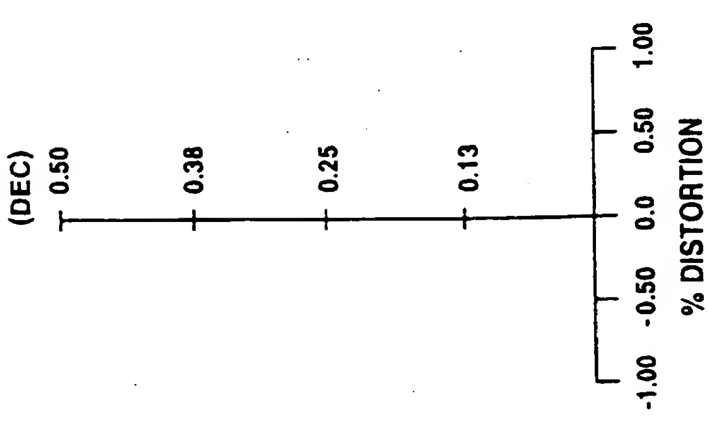
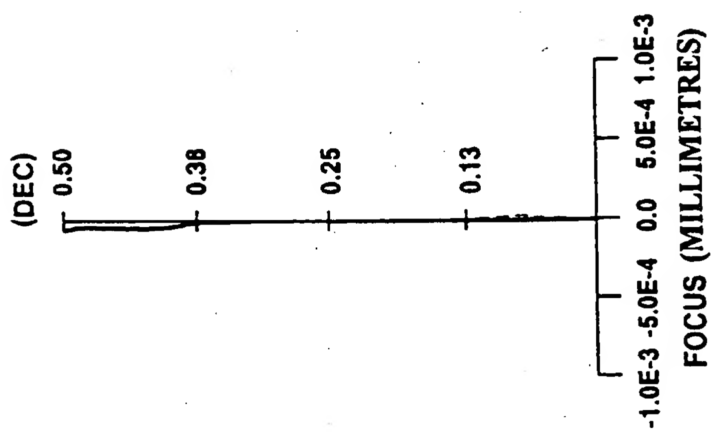


FIG.98



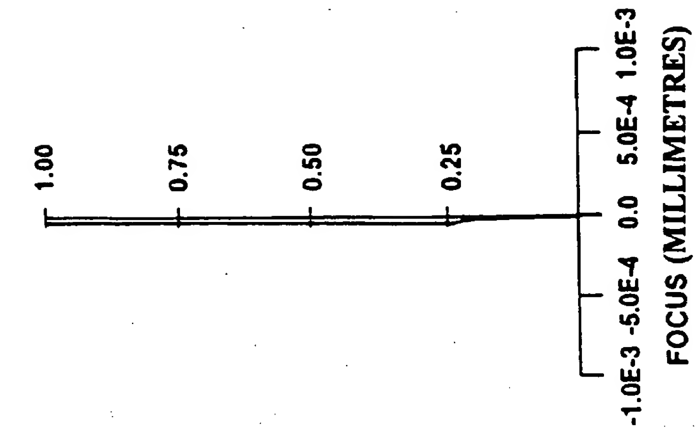
DISTORTION

FIG.99



ASTIGMATIC
FIELD CURVES

FIG.100



LONGITUDINAL
SPHERICAL ABER

FIG.101

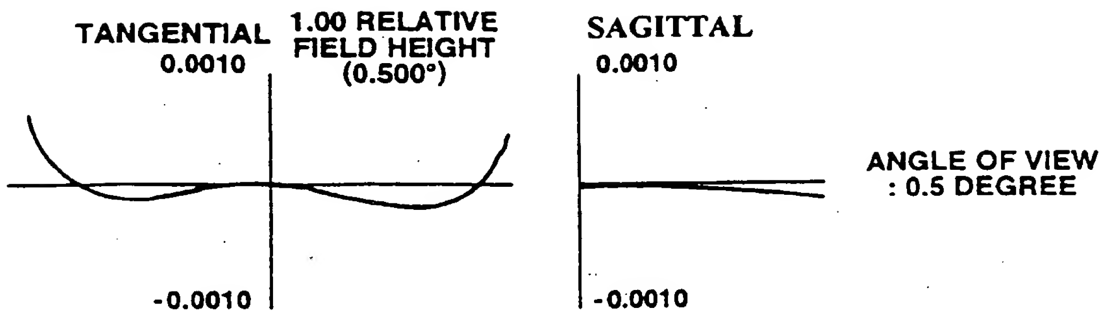


FIG.102

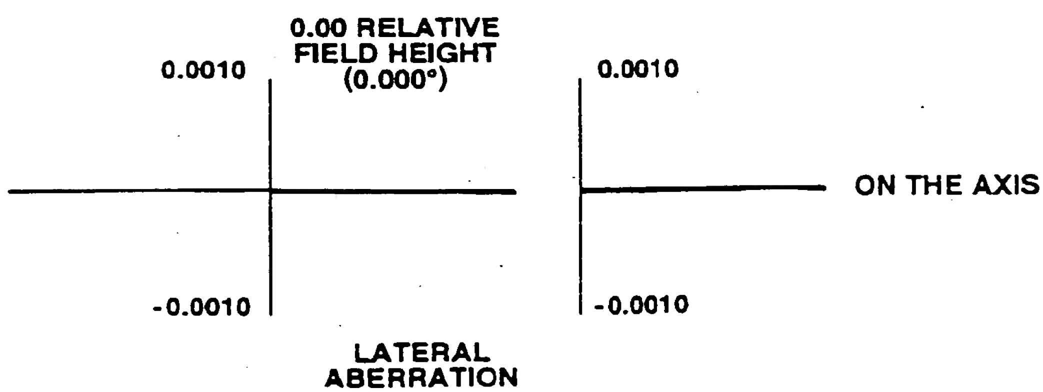


FIG.103

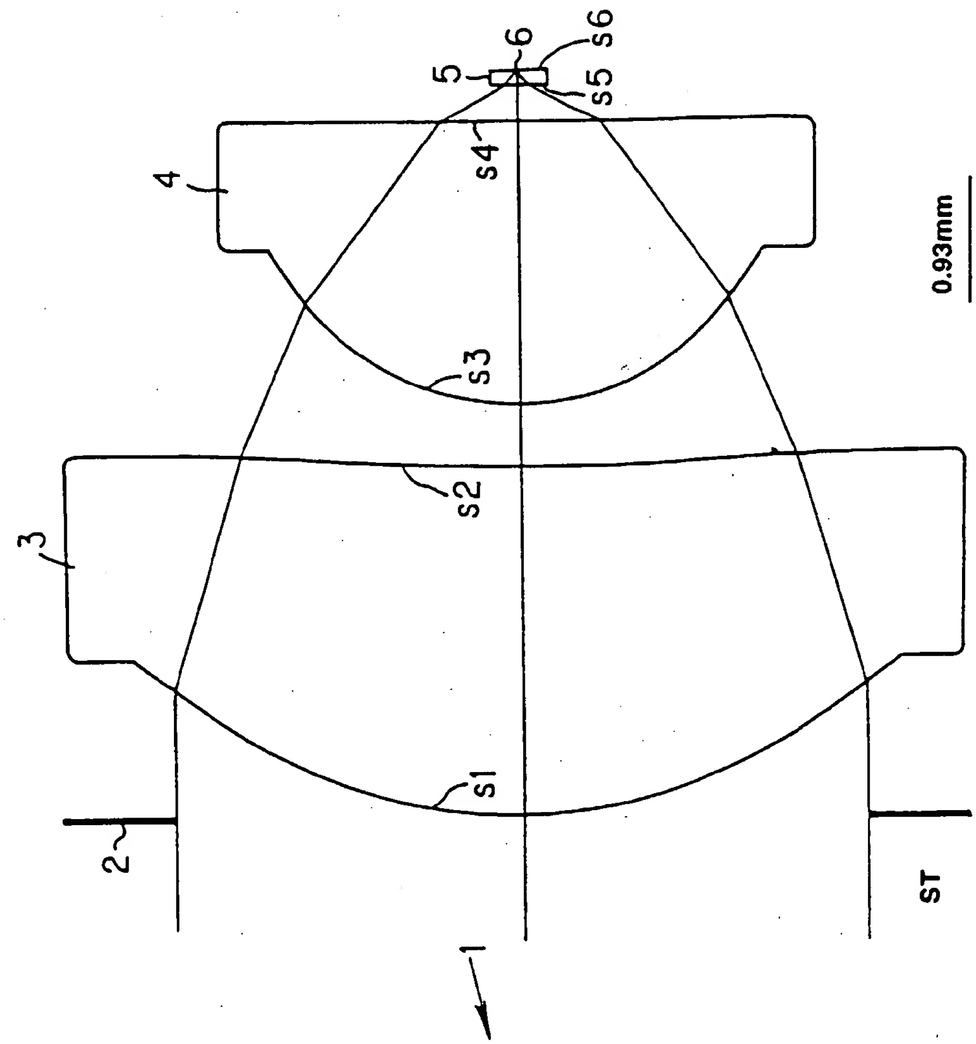
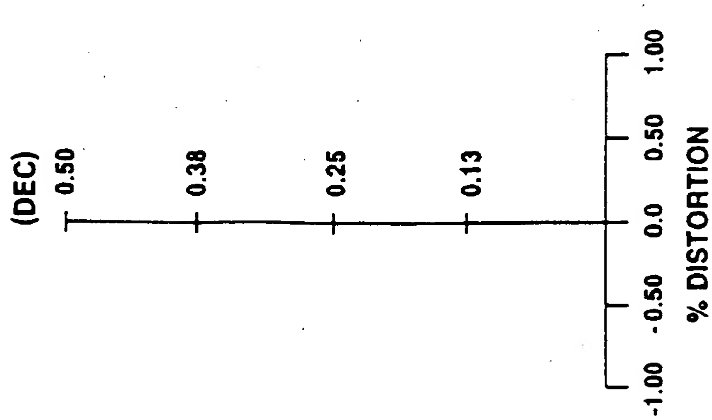
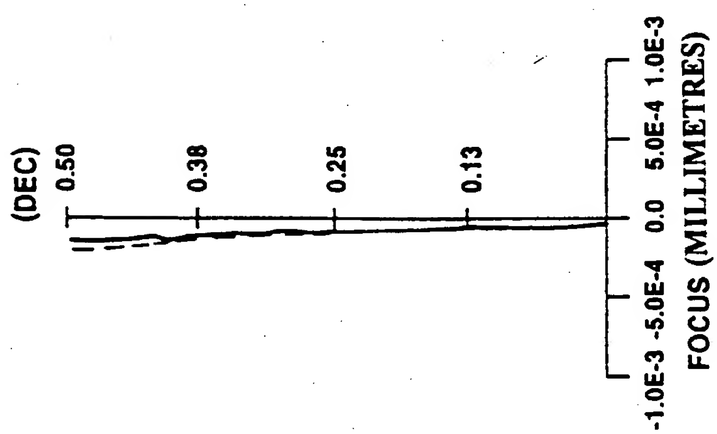


FIG.104



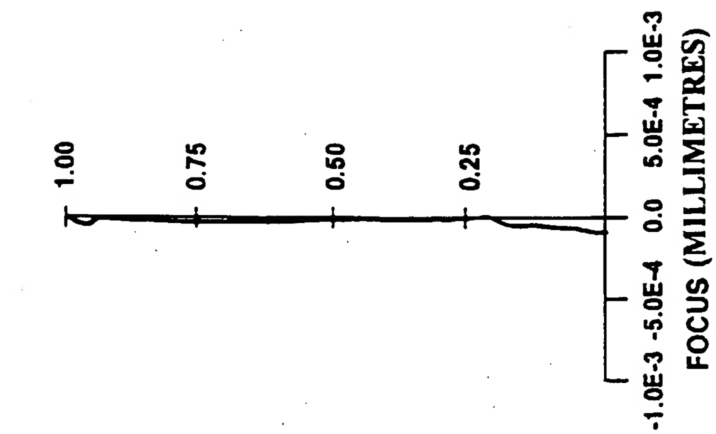
DISTORTION

FIG.105



ASTIGMATIC
FIELD CURVES

FIG.106



LONGITUDINAL
SPHERICAL ABER

FIG.107

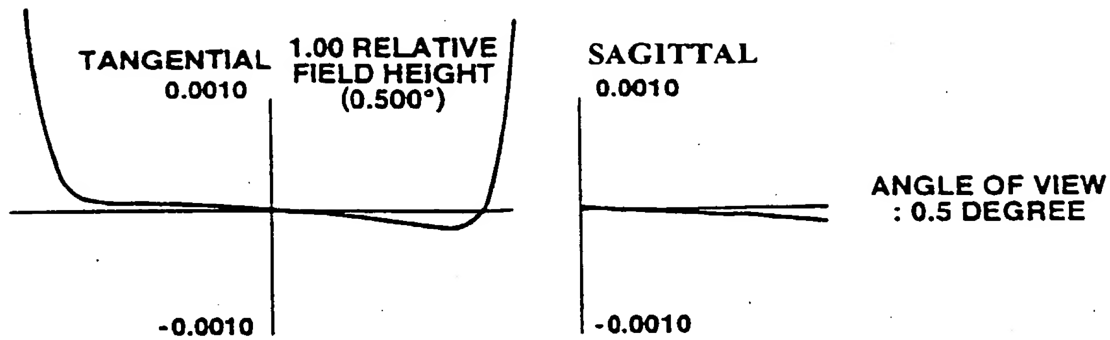


FIG.108

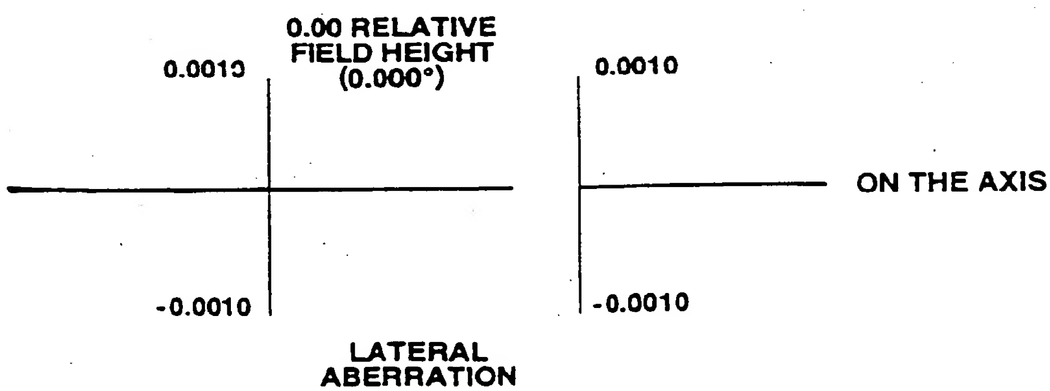


FIG.109

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Office européen des brevets

(11) EP 0 840 156 A3

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06.05.1998 Bulletin 1998/19

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(54) **Objective lens and optical pickup apparatus**

(57) An objective lens having a doublet structure and a numerical aperture of 0.7 or more and an optical pickup apparatus having this objective lens are adapted to an optical recording medium having a high information recording density, the objective lens being structured such that at least one side is formed into a aspheric surface and the lens elements (3, 4) are made of low-diffusion glass having an Abbe's number of 40 or greater.

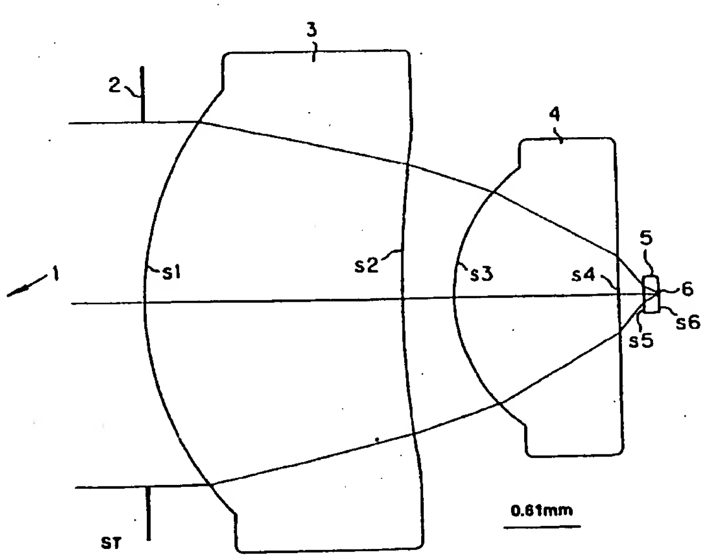

FIG.1

EP 0 840 156 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 40 2530

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	EP 0 727 777 A (SONY CORP) 21 August 1996 * column 5, line 11 - column 6, line 32; figure 2 * ---	1-3,7,8	G02B13/18 G02B9/06 G11B7/135 G02B13/24
Y	US 4 953 959 A (ISHIWATA HIROSHI ET AL) 4 September 1990 * column 6, line 50 - column 7, line 64; figure 5 * ---	1-3,7,8	
A	US 5 467 225 A (MANABE YUJI) 14 November 1995 * first embodiment * ---	1,7	
A	US 5 050 970 A (KITTAKA SHIGEO) 24 September 1991 * column 3, line 54 - column 6, line 25; figures 22-24 * ---	1,7	
A	PATENT ABSTRACTS OF JAPAN vol. 008, no. 271 (P-320), 12 December 1984 & JP 59 140414 A (ASAHI KOUGAKU KOGYO KK), 11 August 1984 * abstract * -----	1,7	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G02B G11B G03B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	25 November 1998	von Moers, F

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